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Vol. 5 JUNE, 1936 No. 5

# The Journal of Thoracic Surgery

Official Organ

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Published Bi-Monthly by
The C. V. Mosby Company, 3523 Pine Blvd., St. Louis, U. S. A.

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Vol. 5, No. 5, June, 1936. Journal of Thoracic Surgery is published bi-monthly by The C. V. Mosby Company, 3523 Pine Blvd., St. Louis, Mo. Subscription Price: United States, its Possessions, Pan-American Countries, Canada, $7.50 a Year; Foreign, $8.00. Entered as Second-Class Matter at Post Office at St. Louis, Mo., Under Act of March 3, 1879.

# The Journal of Thoracic Surgery

VOL. 5 JUNE, 1936 No. 5


## Original Communications

### COMPLEMENTARY ANTERIOR THORACOPLASTY FOR PULMONARY TUBERCULOSIS

#### A TECHNIC EMPLOYING PARASTERNAL DIVISION OF THE COSTAL CARTILAGES*


CAMERON HAIGHT, M.D.
ANN ARBOR, MICH.


RECENT improvements in the technic of thoracoplasty have so greatly increased its effectiveness and safety that it is now possible to close practically all unilateral tuberculous cavities with a minimal mortality. In cases presenting refractory cavities and a less than average operative risk, the most satisfactory results can be obtained by the inclusion of anterior thoracoplasty as an integral part of the operative program.

Anterior thoracoplasty in the past has possessed certain objectionable features which, it is believed, have been largely overcome by a technic that will be described. The results of this technic in a series of 50 cases show an increased percentage of cavity closures (92 per cent). An important reduction of operative mortality (0 per cent) and a decrease of postoperative morbidity have also resulted from the resection of shorter lengths of the upper ribs at the more dangerous posterior stages, the remaining stumps of these ribs being removed at the anterior stage. The indications for anterior thoracoplasty, certain technical considerations pertaining to the posterior stages of the thoracoplasty in their relation to the anterior stage, and brief mention of two other technics for anterior thoracoplasty now in use at the University of Michigan Hospital will also be described in this article.


*From the Department of Surgery, University of Michigan.



The preparation of this report was aided by the Doctor George Alexander Fleming Fund for Thoracic Surgery.

Received for publication, March 4, 1936.

## INDICATIONS

The indications for anterior thoracoplasty may be segregated into three groups pertaining to: (1) the reduction of operative mortality and morbidity; (2) the closure of cavities; and (3) the accomplishment of an increased selective collapse of the upper portion of the lung.

*The Reduction of Operative Mortality and Morbidity.*—The posterior resection of the upper three ribs to their costal cartilages exposes many patients to considerable dangers, because of the paradoxical motion of the newly decostalized anterior thoracic wall, as well as the sudden great collapse of the thoracic wall. The paradoxical motion of the anterolateral portion of the hemithorax that occurs after the first stage, and more importantly after the second or third stages of the posterior thoracoplasty, may result in severe and at times fatal cardiovascular or respiratory complications. Furthermore, the flail anterior thoracic wall does not provide the support that is advantageous in promoting efficacy of cough and expectoration at the time when there may still be considerable sputum. As a result, a spread of the disease may occur, owing to the patient's inability to expel secretions from the tracheobronchial tree. Untoward experiences such as those mentioned above have been noted in this clinic among a few patients in whom the uppermost ribs have been resected as far as their cartilages at the first stage. Because of these dangers it is inadvisable except in rare instances to resect the upper three ribs to their costal cartilages at the first posterolateral stage of the thoracoplasty.

When a great collapse of the upper portion of the lung is needed in patients judged to be inferior operative risks, as determined by the criteria about to be mentioned, it is believed that the collapse can be obtained with a far greater margin of safety by the staging of the thoracoplasty in the *horizontal* direction, as well as in the customary *vertical* direction. If this policy is applied, anterior thoracoplasty is indicated for patients who are obviously inferior risks because of age, tuberculous toxicity or inadequate cardiorespiratory reserve. Other indications for the division of the costal resection into posterolateral and anterior stages are: a large amount of sputum and, more especially, difficulty in raising the sputum; marked retraction of the mediastinum and kinking of the trachea sufficient to cause symptoms; preoperative dyspnea, due either to emphysema, cardiac disease, contralateral fibrosis or tuberculous infiltration, or to contralateral collapse therapy; and, lastly, excessive paradoxical motion observed during the course of the first posterior stage, i.e., after removal of the posterior segments of the second or third rib, as is not uncommonly seen in cases with an underlying pneumothorax and with only slight pulmonary and pleural fibrosis.

*The Closure of Cavities.*—Certain cavities require maximum collapse in order to obtain and maintain their closure. The amount of collapse

in such instances must of necessity be greater than that which is produced by the removal of the uppermost ribs to their costochondral junctions. This additional collapse can be readily accomplished by the division or the resection of the costal cartilages at an anterior stage.

An effective posterolateral thoracoplasty consists of a complete resection of the upper two or three ribs and partial removal of as many additional ribs as the individual case requires. The vertebral transverse processes, with the exception of the first, are totally or subtotally resected. Although the tremendous collapse that results from this posterior operation will close a large percentage of pulmonary cavities without the aid of an anterior stage, it is believed the latter is highly desirable almost as a routine measure in a minimal group of cases with large or mammoth cavities. Even with cavities of moderate size, certain preoperative indications suggest the possible necessity of an anterior stage to secure maximum collapse. These indications are a progressive enlargement of the cavity and, at times, the lack of any tendency for spontaneous closure as seen in serial films; a mesial location of the cavity; a stiff-walled cavity of long duration and, finally, the absence of appreciable evidence of fibrosis.

The need of additional collapse may not be realized until the posterior stages of the thoracoplasty have been completed. Cavities of only moderate size not infrequently remain open three or four weeks after completion of the type of posterior resection described above. One then has the choice of waiting to determine whether the cavity will close without additional collapse, or of proceeding directly with an anterior operation in order to secure the additional collapse before stiffening of the decostalized part of the thoracic wall occurs. The latter policy is usually preferable, for, if it is to be performed at all, the anterior stage should be done before the decostalized thoracic wall has become unduly stiffened and before bone regeneration has occurred, should the periosteum not have been formalinized. If undue rigidity of the posterolateral thoracic wall has already occurred when the anterior stage is performed, the effectiveness of the anterior operation will be greatly lessened.

*Increased Selective Collapse.*—A further indication for anterior thoracoplasty exists when a maximum selective collapse is desired for lesions limited to the upper third of the lung. After the accomplishment of maximum collapse of the diseased area, the posterior partial thoracoplasty need not be carried as low as would otherwise be necessary. This policy allows the preservation of a greater degree of function of an undiseased lower lung which is of advantage from a physiologic standpoint and which may necessarily be required because of contralateral disease or collapse therapy. The performance of a permanent phrenic nerve interruption becomes not only unnecessary but inadvisable when the selective thoracoplastic collapse has adequately controlled lesions that are restricted to the upper portion of the lung.

## TECHNIC

A technic of anterior thoracoplasty that will be presented was developed because the technic previously employed in this clinic possessed certain objectionable features. The earlier technic[1] consisted of resection of the costal cartilages and the anterior costal segments. In most cases it resulted in a permanently unstable anterior thoracic wall due to failure of the perichondrium to develop firm cartilage. The absence of chondrogenesis was an almost constant clinical observation. This finding has been corroborated experimentally by Bisgard,[2] who demonstrated that the subperichondrial resection of the costal cartilages results in a constant failure of the dechondralized portions of the thoracic wall to regain normal preoperative skeletal rigidity. The residual perichondrium formed only a few small islands of fibrocartilage, chondrogenesis having played an almost negligible part in the reparative process. The permanently soft anterior wall in the group of cases operated upon by the chondrectomy technic was of clinical importance, since some of the patients were required to wear a thoracoplasty brace for an indefinite period in order to maintain the desired collapse and to support the flail thoracic wall during cough and expectoration. Furthermore, the deep anterior depression resulting from resection of the cartilage was unsightly and objectionable.

Because of these disadvantages of chondral resection, the principle of parasternal division of the costal cartilages, without their resection, was applied to anterior thoracoplasty. This principle was originally suggested by Eden[3] and Wilms,[4] and later by Gale.[5] Gale recommended parasternal division of the cartilages, without resection of the cartilages or the anterior costal segments. This technic was used in seven cases. An improved collapse resulted in the majority of these cases, but it was not completely satisfactory because of the remaining anterior costal stumps. Therefore, the technic as such was discontinued, but the principle of parasternal division of the cartilages was retained. The following technic was then evolved. Since its introduction in this clinic in December, 1932, it has been used without important modifications in 50 cases.

The technic in brief consists of resection of the anterior costal stumps and parasternal division of the costal cartilages (Fig. 1). Division of the cartilages allows them to hinge at the sternum, so that they are free to swing mesially and posteriorly, thereby increasing the collapse. As the first rib will have been routinely resected to, and often including, its cartilage at the upper posterior stage, it is necessary to resect only the residual anterior segments of the second, third, and usually the fourth ribs. The second and third (and rarely the fourth) costal cartilages are divided at their sternal attachments. As these cartilages are not resected, eventual stability of the thoracic wall is readily ob-

tained, and the thickness of the retained cartilages decreases the amount of anterior deformity. The first cartilage is, however, resected if it has not been removed at the first posterior stage; mere division is impracticable because of the firm superior attachments. Furthermore, the removal of only the first cartilage does not interfere with the permanent stability of the thoracic wall at this level.

The details of the technic are as follows: With the patient lying on his back, a small sand bag or pillow is placed beneath the side to be operated upon, so that rotation of about 15 degrees toward the contralateral side is obtained. An assistant holds the arm in abduction, so as to displace the axillary vessels upward and away from the operative field. Nitrous oxide and oxygen inhalation anesthesia is used. A semi-

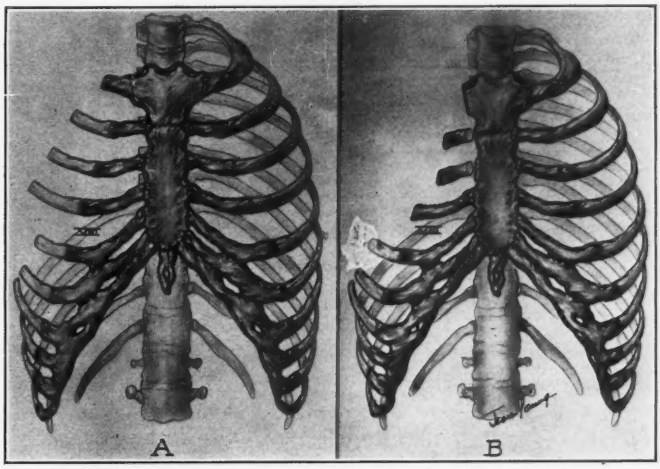


Fig. 1.—*A*, Diagram illustrating the extent of the posterior resection prior to a contemplated anterior thoracoplasty. The transverse processes of the vertebrae have been almost totally resected. The first rib has been completely resected, but moderately long stumps of the second, third, and fourth ribs remain in place to serve as an anterior support.

*B*, The anterior costal stumps (second, third, and fourth) and the first costal cartilage have been resected at the anterior stage. In addition, the second and third cartilages have been divided at their sternal attachments, allowing them to swing mesially and posteriorly and increasing the anterior collapse.

lunar anterior axillary incision, as described by Alexander,[1] is customarily employed. The incision begins 2 or 3 cm. mesial to the lateral border of the pectoral fold and 9 or 10 cm. below the clavicle. It extends inferiorly and laterally along the anterior axillary line and then curves mesially beneath the breast for 4 or 5 cm. The lateral border of the pectoralis major muscle is exposed in the upper portion of the incision, and the axillary contents are pushed laterally by blunt dissection. The exposed costal attachments of the pectoral muscles are divided, and the pectoralis major muscle is retracted mesially and anteriorly by a

long bladed retractor. The assistant now adducts and slightly internally rotates the arm so as to relax the pectoralis major and facilitate its retraction.

The next step in the operation is the subperiosteal removal of the anterior stumps of the second, third, and usually the fourth ribs that were not resected at the posterior stages. The first rib will have been completely and more easily resected at the upper posterior stage. Formalinization of the periosteum at the anterior stage is not performed, since early bone regeneration is desirable.

The second and third costal cartilages are divided at their sternal attachments. The fourth cartilage may occasionally need to be divided

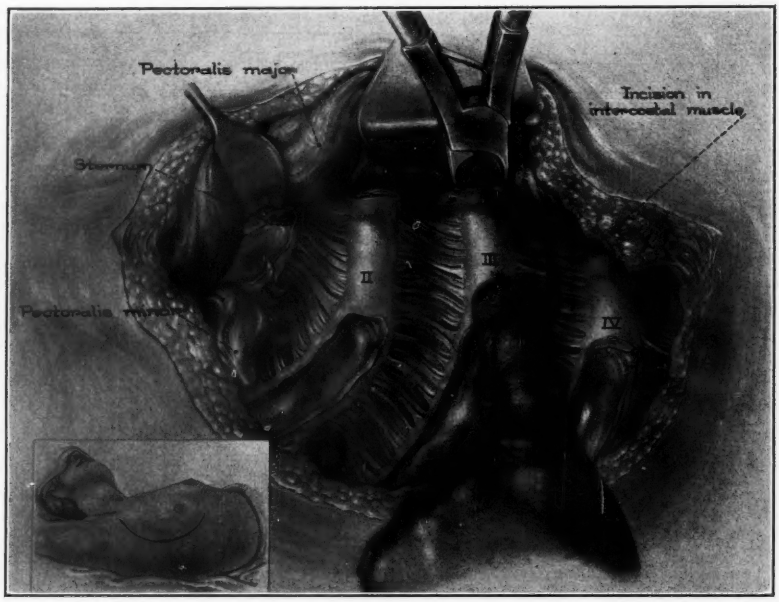


Fig. 2.—Drawing illustrating the technic of anterior thoracoplasty. The second, third, and fourth anterior costal stumps and the first cartilage have been resected. The second cartilage has been divided and is now hinged at the sternum. Pressure upon the cartilage which is being divided will demonstrate when it has been completely severed. An incision through the intercostal muscle between the lowest divided cartilage and the adjacent intact cartilage will allow the divided cartilages to fall inward to better advantage. The insert shows the anterior axillary incision which is customarily employed for anterior thoracoplasty (from John Alexander[1]).

if the pulmonary lesion requires the additional collapse. A rib shears, scalpel, or small rongeur with curved points may be used for dividing the cartilages. When a scalpel is employed, the excision of a narrow wedge of cartilage allows a better estimate of the depth of the incision. The removal of a wedge aids in preventing injury to the subjacent structures. The incision need not be made completely through the innermost portion of the cartilage which can be readily fractured by the

forceful rotation of a blunt periosteal elevator inserted into the partially incised portion of the cartilage. The inner layer of the perichondrium is not incised. Backward pressure upon the cartilage during its division (Fig. 2) will demonstrate when it has been completely severed, as the cartilage will then swing freely mesially. When the cartilages are incised parasternally, small anterior perforating branches of the intercostal vessels which lie immediately above and below the cartilages at the level of the incision may be injured. They can be more readily controlled with electrocoagulation than by suture or ligature. A relaxing incision through the internal intercostal muscle between the lowest divided cartilage and the adjacent intact cartilage has been used in the recent cases in this series. The intercostal incision which extends down to the pleura allows the lowest divided cartilage to fall inward to a greater degree.

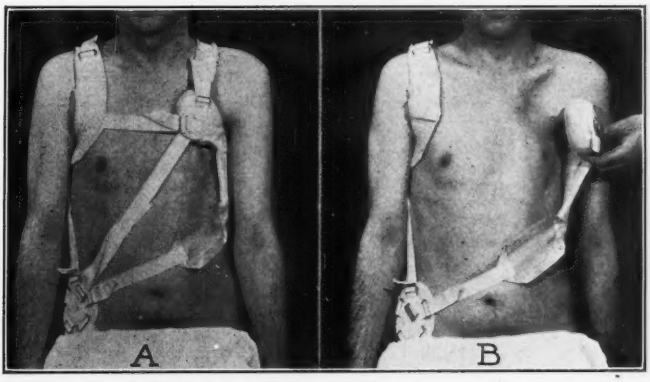


Fig. 3.—*A*, Thoracoplasty brace with a sponge rubber pad to increase the anterior collapse is applied from seven to ten days after operation and is worn until costal regeneration has resulted in a firm anterior thoracic wall (brace designed by Warriner Woodruff[8]).

*B*, The anterior pad been displaced to illustrate its thickness. The infraclavicular depression is less pronounced when the cartilages have been preserved than when they have been resected.

The resection is now complete except for removal of the first cartilage in case it has not already been removed at the upper posterior stage. The lateral end of the cartilage is exposed by sharp dissection. The perichondrium is divided along the inferior margin of the cartilage and a narrow lateral portion of the cartilage is removed with rongeurs in order more readily to identify the posterior subperichondrial cleavage plane. By the alternate subperichondrial separation and rongeuring away of small portions of cartilage, the first cartilage is completely resected until the cancellous sternum is exposed. If the cartilage is cautiously removed in this manner, injury to the subclavian vein and the internal mammary vessels is avoided. The incision is closed in layers. The wound is drained for twenty-four hours with a soft rubber drain

in the lower angle of the incision. A firm pressure bandage is applied to prevent the accumulation of serum, and a three-pound shot bag is placed over the dressing to afford additional pressure. After removal of the skin sutures, a thoracoplasty brace[6] (Fig. 3) with an anterior pad is applied to increase the anterior collapse and should be worn until the regeneration of the anterior ribs markedly stiffens the anterior thoracic wall.

A parasternal incision (Bérard and Dumarest[7]) (Fig. 4) provides an excellent exposure, especially for the parasternal division of the cartilages, and may be used as an alternative to the anterior axillary incision. As the resultant scar is conspicuous, this incision has not been used in our recent cases, since the anterior axillary incision provides ample exposure. The parasternal incision is made along the lateral margin of the sternum from the first to the third or fourth cartilage.

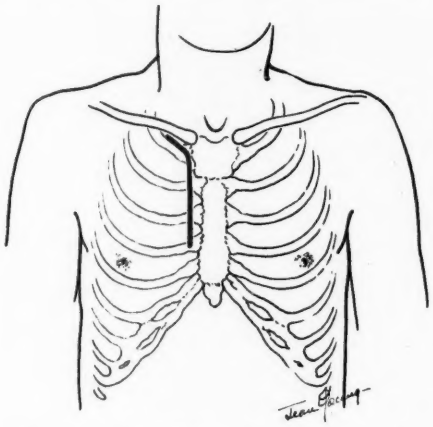

Fig. 4.—The parasternal incision of Bérard and Dumarest[7] is rarely employed, as the scar is conspicuous. The exposure with this incision is, however, more easily obtained than with the anterior axillary incision. The parasternal incision is preferable for the type of anterior thoracoplasty described by Bisgard.[2]

The incision is extended upward and outward beneath the clavicle so that sufficient exposure may be obtained for resection of the first cartilage, should it not have been removed at the upper posterior stage. The extent of the resection and the division of the cartilages are the same as those described above. Drainage of the wound is not employed.

The advisability of resection of the fourth and, possibly, the fifth anterior costal stumps, with or without the parasternal division of the fourth cartilage, depends upon the amount of collapse required, as determined by the size, location, and type of the pulmonary lesions. Whether or not this additional resection should be deferred to an additional stage depends upon certain criteria. These include the development of dyspnea, a low vital capacity, excessive paradoxical motion

which is unusual at the anterior stage, or the continuance of such symptoms as originally suggested the need of an anterior thoracoplasty as a measure to reduce operative mortality and morbidity. An anterior thoracoplasty is customarily performed in two stages only in cases of large tuberculous empyemas when the removal of the upper six or seven anterior costal stumps is required to obliterate the empyema cavity.

The postoperative convalescence following anterior thoracoplasty is smoother than that following the posterior stages, even when only two ribs have been resected at each posterior stage. The explanation for this is apparently the fact that, other conditions being equal, the postoperative reaction varies proportionately with the amount of pulmonary

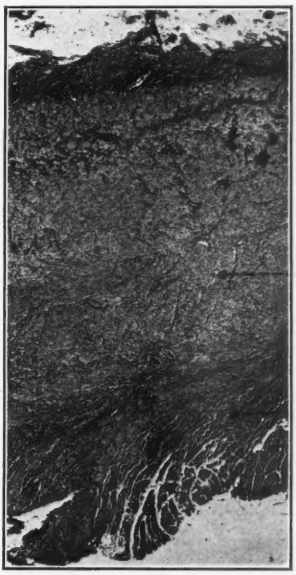


Fig. 5.—Relatively thick fibrous tissues (×15) found immediately lateral to the anterior costal stumps in the region where the lateral portion of the third rib had been removed at the first posterior stage nine weeks previously. The scar tissue, which is thicker than usual in this case, accounts for the relative absence of paradoxical motion during and following the anterior stage of the thoracoplasty. *A*, Subpectoral space; *B*, granulation tissue; *C*, scar tissue; *D*, intercostal muscle.

collapse produced at any given stage. In contrast to each posterior stage, the actual amount of collapse resulting from the anterior stage is not so great, although this additional collapse may mean the difference between success and failure in the obliteration of the pulmonary cavity.

Although excessive and dangerous paradoxical motion is not infrequently observed when tremendous lengths of the upper ribs are removed at the posterior stages, paradoxical motion of clinical importance has been observed in only one case following anterior thoracoplasty. The resection included the second, third, and fourth ribs and division

of the corresponding cartilages. In retrospect, the performance of the anterior operation in two stages would have been preferable in this case.

The relative absence of paradoxical motion during and following the anterior stage is due to the fibrous thickening (Fig. 5) of the decostalized posterolateral thoracic wall that results from deposition of fibrin in the posterior wound. The fibrosis produces stability, but not rigidity, of the thoracic wall lateral to the anterior segments to be removed. The routine use of 10 per cent formalin[8, 9] on the periosteum of the subscapular portions of the upper ribs resected at the posterior stages will have prevented their regeneration. The fibrous thickening does not impair the anterior collapse unless there has been a prolonged interval between the upper posterior stages and the anterior stage, or unless the posterior wound has been infected.

The optimal time for the performance of the anterior stage is after the posterior resection of sufficient ribs (six or seven) to allow the scapula to fall forward. The anterior displacement of the scapula maintains the collapse of the upper portion of the lung and tends to prevent paradoxical movement of the underlying thoracic wall; without it, the lung partially and gradually expands as a result of the absorption of serum and air from the subscapular wound. As the upper posterior stages with their resultant scapular displacement produce a greater degree of collapse than does the anterior stage, the latter is deferred until the more important posterior collapse has been obtained. If a total posterior thoracoplasty is needed, the lower ribs (eight, nine, ten, and eleven) are resected after the intervening anterior stage. Should an anterior thoracoplasty be indicated for an anterior apical or subapical cavity, for which less than six or possibly seven ribs need be resected posteriorly, it is advantageous to resect the lower portion of the scapula[10] so that it will not be held outward, or elevated by the uppermost intact rib. The desired collapse can thereby be obtained with a minimal posterior resection and with the resultant greater preservation of pulmonary function.

The possible objections to anterior thoracoplasty should be mentioned, although they appear to be trivial when compared with the advantages. The obvious objections are the necessity of an additional operation and incision, and the greater amount of anterior deformity. With regard to deformity, it should be recalled that a complete costectomy of the upper two or three ribs, performed entirely posteriorly, likewise results in a certain but lesser anterior depression. Also the depression following anterior chondroplasty is invariably less than that following anterior chondrectomy, resulting in part from the thickness of the retained cartilages.

Bleeding was encountered during division of the cartilages in two early cases. The need for an electrosurgical unit had not been anticipated, and since one was not available, it was necessary for the surgeon

to resect the cartilage in order to control the bleeding. These two cases are not included in this series, because the second cartilage was resected in each instance.

### TECHNIC OF THE POSTERIOR THORACOPLASTY

Conservatism in the number and lengths of ribs resected at each of the posterior stages is of great importance in the lowering of the operative mortality. We feel that it is dangerous to resect as much as the total lengths of three ribs at any one of the posterior stages. For this reason, in this clinic, the number of ribs resected at the upper posterior stage is now limited to two, or two and a short posterior segment of the third. The remaining anterolateral segment of the third rib is removed at the following stage at which time, again, not more than the equivalent lengths of two, or two and a half ribs are resected. A three-stage thoracoplasty would therefore include the resection of six, seven, or rarely eight ribs, depending upon the lengths resected and other factors. Four posterior stages are not rarely required for an extensive posterior thoracoplasty.

The removal of the first and second ribs to their cartilages at the first stage has not been accompanied by untoward complications. As subsequent ribs are removed, however, caution must be exercised regarding the lengths resected. The number and lengths of ribs removed at any given stage are determined by the preoperative vital capacity, the amount of collapse produced, as observed during the course of the operation and by the presence or absence of excessive paradoxical motion, the stiffness of the underlying pleurae and lung, and the general condition of the patient.

By the removal of not more than two or two and a half ribs at each of the posterior stages, it is possible to resect relatively great lengths with increased safety and to obtain closure of cavities without the use of anterior thoracoplasty in a large percentage of cases that do not require maximum collapse. It is believed that this plan is preferable to the use of anterior thoracoplasty in the majority of cases, provided it can be done without subjecting the patient to increased risks from the development of excessive paradoxical motion following the second and third stages, and provided the amount of collapse is adequate.

*The Avoidance of Excessive Paradoxical Motion.*—Excessive paradoxical motion sufficient to produce untoward complications may obviously be caused by the removal of too many ribs at each stage. With careful staging of the posterior thoracoplasty, this complication rarely occurs except when too great lengths of the third, fourth, and fifth ribs have been resected posteriorly. This region is the dangerous zone for the development of paradoxical motion, which may occur not only after the resection of these ribs but more especially after the subsequent posterior stage. In order to avoid the development of excessive para-

doxical motion, long anterior segments of the second, third, and fourth ribs, or of only the third and fourth ribs, are temporarily allowed to remain as a support, and are later removed at an anterior stage. In the interim, the necessary lengths of the fifth, sixth, and seventh ribs can be safely resected posteriorly. The optimal collapse is thereby obtained with a minimal amount of paradoxical motion and with increased safety.

Resection of the vertebral transverse processes[11] is an integral part of the posterior thoracoplasty and greatly increases the collapse of the deep costovertebral gutter, which is frequently the location of a pulmonary cavity. It is usually unnecessary to resect the first transverse process, but care should be taken to remove all or virtually all of the several transverse processes at, above, and below the level of the pulmonary cavity.

Chemical treatment of the periosteum is routinely used to prevent or delay costal regeneration. Thus, the interval between stages can be lengthened if necessary, without fear of costal regeneration occurring too early. The costal periosteum of the portion of the thoracic wall covered by the scapula is thoroughly rubbed with 10 per cent formalin,[8, 9] an especially advantageous precaution if an anterior stage is to be used, since an anterior stage will be less effective if performed after costal regeneration has occurred posteriorly.

An interval of about three weeks has been found to be the preferable period between the stages of the thoracoplasty, although in a few cases it may be advisable to prolong the interval.

## RESULTS

The technic of the anterior thoracoplasty described in this article has been used for 50 patients, or 35.4 per cent of the 141 thoracoplasty patients operated upon during the period covered by this report (December, 1932—October 1, 1935). The results will be classified only in regard to cavity closure and the presence or absence of tubercle bacilli in the sputum, as the operations in some of these cases have been performed too recently for the patients to have returned to work. Nineteen additional patients have been operated upon without mortality during the past five months. These cases are not included as it is believed that a sufficient time has not elapsed to allow proper evaluation of the results.

Positive sputum and roentgen evidence of a pulmonary cavity were present in every case before operation. In six of the 50 patients there was a pure tuberculous empyema, the result of an induced and unsuccessful pneumothorax. The anterior operation was performed in conjunction with a secondary posterior thoracoplasty (a complete reoperation) in three cases, the original posterior thoracoplasty having failed to close the pulmonary cavity. Measurement of the pulmonary cavities in the 50 cases, as seen in the roentgenograms, showed their greatest

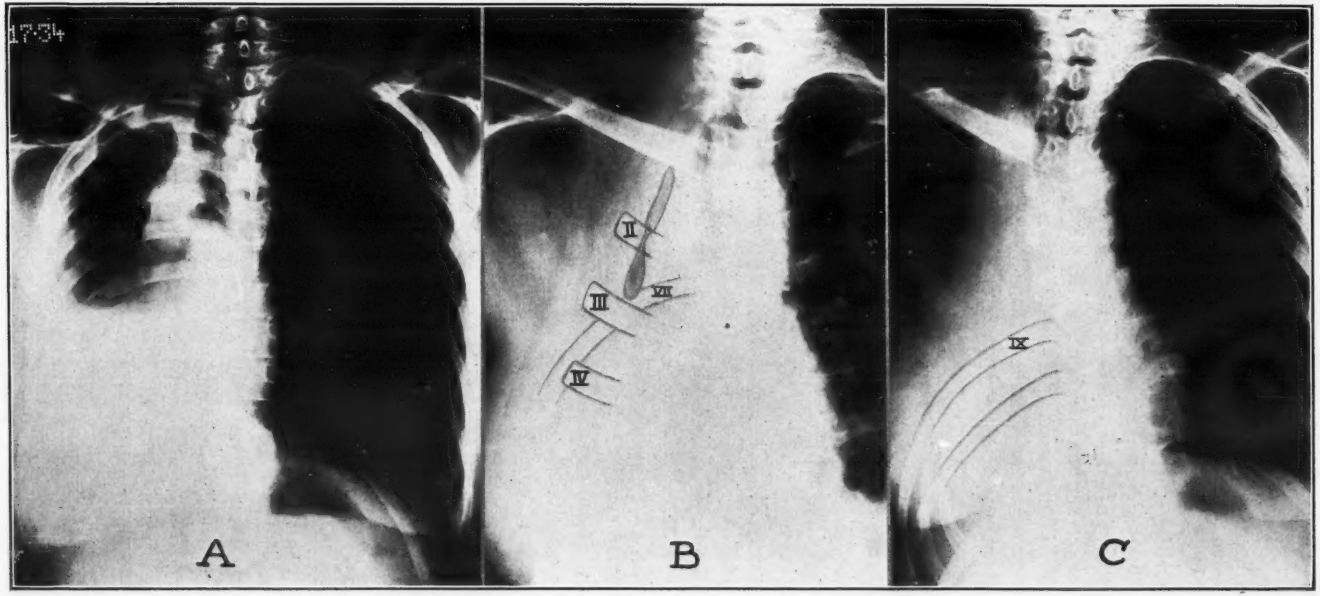


Fig. 6.—*A*, Mammoth right intrapulmonary cavity (11.3x8.0 cm.); tuberculosis of seven years' duration; 90 to 140 grams positive sputum. Pneumothorax could not be obtained. No history of spontaneous pneumothorax.

*B*, Roentgenogram following the removal of the posterolateral portions of the upper six ribs. The large cavity has been reduced to a slit (retouched). The anterior stumps of the second and third ribs (also retouched) overlie the cavity. The long stumps of the second to fourth ribs were purposely allowed to remain at the posterior stages as the patient had a large amount of sputum, difficulty in expectoration, and a low vital capacity (1300 c.c.).

*C*, Complete closure of the cavity has occurred after the fourth posterior stage with resection of the seventh and eighth ribs and a subsequent anterior stage, which included the resection of the second to fourth costal stumps and the first cartilage, and the parasternal division of the second to fourth costal cartilages.

diameter to be 7 cm. or more in eight (16 per cent) of the 50 cases, and between 5 and 7 cm. in eleven (22 per cent). In the remaining 31 cases (62 per cent), either a single cavity less than 5 cm. or multiple small areas of cavitation were seen. The largest cavity (Fig. 6) measured $11.3 \times 8$ cm.

Closure of cavities and negative sputum have resulted in 46 (92 per cent) of the 50 cases. There has been no operative mortality and no late mortality due to tuberculosis. The general condition of the four patients with positive sputum has been improved by operation. In the first patient, an Indian, who had a rapidly enlarging cavity before operation, the cavity remained closed and the sputum negative for nineteen months after operation. Positive sputum on culture but not on concentration and probable reopening of the cavity have recently occurred in spite of an excellent thoracoplastic collapse. In the second patient, a residual cavity has always been evident in the postoperative roentgenograms. The thoracoplastic collapse is not adequate because of pleural thickening rather than costal regeneration. An extended period between the first and second posterior stages was necessitated in this case because of an increase of a preexisting tuberculous infiltration in the contralateral lung. The third patient had two cavities which increased slightly in size following a temporary phrenic nerve interruption. After the thoracoplasty the sputum became negative for eight months, but it has recently become positive on culture, although it remains negative on concentration. Roentgenograms show a probable reopening of the larger of the two cavities. The fourth patient has had a bilateral thoracoplasty with an anterior stage on the more involved side. A residual cavity cannot be seen in numerous roentgenograms, and bronchoscopy has been of no aid in differentiating the side from which the constantly positive sputum arises. It has not been possible to provide the desired collapse of either lung because of the development of mild dyspnea.

In an additional and early case, a poor posterior collapse resulted because of unintentional failure to formalinize the periosteum at the posterior stages. The cavity, $7 \times 6.5$ cm. before operation, remained open, but it has closed and the sputum has become negative following a reoperation with resection of the regenerated ribs posteriorly. It was unnecessary to reoperate anteriorly, as the anterior collapse was satisfactory. In two more recent cases with residual positive sputum, the posterior collapse has had to be augmented by a secondary thoracoplasty with resection of the several partially regenerated ribs, in addition to the removal of the two adjacent and previously unresected ribs. In each of these cases the sputum is now negative and the cavity closed.

Late deaths from causes apart from pulmonary tuberculosis have occurred in three patients with closed cavities and negative sputums. One patient with paranoid tendencies committed suicide twenty months

after operation; another patient died of a rapidly extending carcinoma of both breasts with metastases, and the third patient died of acute intestinal obstruction eighteen months after operation. In the last case, a colored male fifty-six years of age, necropsy showed no evidence of residual cavity. The other two patients died after discharge from their sanatoriums, and necropsies were not obtained.

In contrast to the absence of operative mortality in the group of cases with anterior thoracoplasty, three patients who did not have the benefit of staged anterior and posterior resections died of complications resulting from excessive paradoxical motion. These three patients were operated upon during the early period covered by this report, the upper three ribs having been resected to their cartilages by the posterior approach.

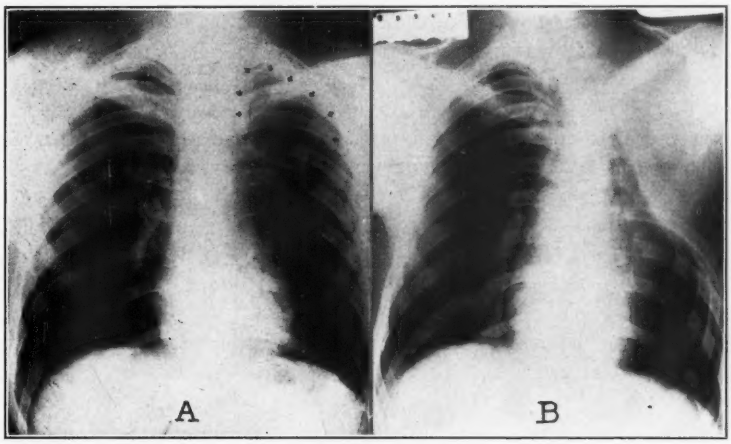


Fig. 7.—*A*, Large left upper lobe cavity (8.7 by 6.7 cm.) prior to a three-stage posterolateral and a complementary anterior thoracoplasty. There is no active tuberculous disease in the lower half of the lung. Pneumothorax could not be obtained. The cavity increased in size in spite of temporary interruption of the phrenic nerve on two occasions. Function of the diaphragm has again returned.

*B*, Roentgenogram four months after completion of the thoracoplasty. Selective extrapleural collapse has resulted in closure of the cavity and negative sputum. The removal of only the uppermost seven ribs and the retention of diaphragmatic function have preserved for this patient most of the function of the lower lung. The collapse of the upper portion of the lung has been augmented by the anterior resection of the second to fourth costal stumps and the first cartilage, and by the parasternal division of the second and third cartilages.

The extent of the anterior chondroplasty has varied according to the pulmonary lesions and other conditions. In the majority of the cases the parasternal division of the cartilages has included only the second and third. In seven cases, the fourth cartilage has also been divided, and in two instances the parasternal division has been carried as low as the fifth cartilage. On the left side, the third cartilage and the fourth anterior costal stump are not infrequently allowed to remain intact as a protection to the heart.

The resection of the anterior costal segments has usually included the fourth, although on the left side, a 3 or 4 cm. segment of the fourth rib may be allowed to remain as a support. In three cases, the resection has included the fifth rib. As a rule, this is unnecessary and inadvisable, as it may result in excessive temporary instability of the thoracic wall. In two instances seven ribs have been resected anteriorly, each operation having been accomplished in two stages. In one other patient with dyspnea and a low vital capacity, two stages were required for an anterior thoracoplasty that included the third cartilage and the fourth rib.

The additional selective collapse that a complementary anterior stage affords to lesions in the upper portion of the lung has not infrequently made possible the resection of one or two fewer ribs posteriorly than would otherwise have been the case. The corresponding preservation of a greater degree of function of an undiseased lower portion of the lung, small though it may be, is desirable (Fig. 7). The number of ribs resected posteriorly in this series is as follows: In 33 cases (66 per cent), not more than eight ribs were resected; in 13 cases, seven ribs were removed, and in four cases, six ribs. In the remaining 17 cases, nine ribs were resected in nine instances, ten ribs in four, and eleven ribs in four.

The two other technics for complementary anterior thoracoplasty which are used in this clinic will be described briefly. The technic of costal osteoperiosteal grafts, suggested by Bisgard,[2] is employed for cavernous lesions demanding extreme collapse. Bisgard advocates the subperichondrial resection of the costal cartilages with implantation of osteoperiosteal grafts into perichondrial tubes constructed from the residual perichondrium. The implantation of bone grafts into the perichondrial beds results in eventual skeletal rigidity anteriorly, overcoming the disadvantage of the permanently unstable thoracic wall that almost invariably results from the failure of chondrogenesis following resection of the cartilages. In resecting the cartilages, the cancellous sternum is exposed so that bony union will ensue. The osteoperiosteal grafts, 0.5-1.0 cm. or larger in size, are obtained from the anterior costal segments that are resected as part of the anterior stage. This technic has been used in nine cases; in four of the five cases that have been examined more than six months after operation, satisfactory skeletal rigidity has occurred clinically. The remaining four patients were discharged to distant sanatoriums soon after operations, and I have not had an opportunity to examine these patients recently. The technic is more time consuming than that for parasternal division of the cartilages. The preferable incision is a parasternal one, since it affords better exposure of the cartilages.

The third type of anterior thoracoplasty consists of resection of the anterior costal stumps without the resection or the parasternal division

of the costal cartilages. This technic has been used in conjunction with extrapleural thoracoplasty for pure tuberculous empyema resulting from a pneumothorax that had successfully closed the pulmonary cavity. In most of these cases an extensive anterior collapse has not been necessary. Resection of the anterior portions of the ribs at the lower level of a stiff-walled empyemic cavity, in addition to the complete resection of the upper ribs, is, however, not infrequently needed to obliterate the rigid cavity. The operation is conveniently performed through an anterior axillary incision, and in two stages if more than four or five ribs are to be resected anteriorly. In this clinic it has been used for cavernous pulmonary tuberculosis only in rare instances, when but little additional anterior collapse was required.

## SUMMARY AND CONCLUSIONS

1. Complementary anterior thoracoplasty is an important adjunct to posterolateral thoracoplasty in certain cases of pulmonary tuberculosis. It provides the additional collapse necessary to effect and maintain the closure of refractory cavities that cannot be closed by posterolateral thoracoplasty alone.

2. An important reduction of the operative mortality and morbidity has resulted from the staging of the thoracoplasty in a horizontal plane, as well as in the customary vertical plane. The purposeful temporary preservation of the upper anterior costal stumps reduces the incidence of complications that may arise from undue paradoxical motion and flaccidity of the anterior thoracic wall resulting from the resection of too great lengths of the upper ribs at the posterior stages of the thoracoplasty. The relative absence of paradoxical motion after the anterior stage is accounted for by the stiffening of the lateral portion of the decostalized thoracic wall resulting from the formation of fibrous tissue in the field of the posterior resections.

3. A technic for parasternal division of the costal cartilages with resection of the remaining anterior costal stumps is presented. The cartilages, with the exception of the first which is resected, are hinged at the sternum, enabling them to swing posteriorly and mesially, thereby increasing the pulmonary collapse. As the cartilages are not resected, eventual stability of the thoracic wall is obtained, overcoming an objection to the former technic of resection of the cartilages, which in turn resulted in a permanently soft anterior thoracic wall due to failure of the residual perichondrium to develop firm cartilage. Preservation of the cartilages also results in a lesser amount of anterior deformity.

4. Certain technical aspects of the posterior stages of the thoracoplasty, so far as they are related to the anterior stage, are discussed.

5. Mention is made of two other technics for anterior thoracoplasty, and their indications are briefly cited.

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# A CONSIDERATION OF CONTRALATERAL PNEUMOTHORAX AS A COMPLICATION OF INTRATHORACIC OPERATIONS*

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CONTRALATERAL pneumothorax is mentioned by neither Alexander[1] nor Archibald[2] in their consideration of the complications associated with lobectomy. In a rather brief period of time we have observed this complication (contralateral pneumothorax) in three cases. The first two patients died; and, because of our costly experience with them, we believe we were able to prevent a fatal outcome in the third.

We have known for several years that should the mediastinal pleura be ruptured and a free communication between the two pleural cavities result, a decided change in the patient's respiratory act is immediately brought about. In addition there is an embarrassment of the action of the heart, and frequently a sucking noise is heard, especially if the opening between the two pleural cavities is large. Such an accident may occur during the attempt to remove a portion of the esophagus or similar procedures, even though the patient is under positive pressure, and intratracheal anesthesia is used. In the presence of bilateral open pneumothorax both lungs expand poorly, the heart action becomes feeble, and unless forceful introduction of air into the lungs is accomplished, the patient will die because of a cessation of the heartbeat.

## CASE REPORTS

Case 1.—This patient was a male in his late fifties; the left pleural cavity was explored on Jan. 18, 1935, for the possible removal of a primary carcinoma involving the lower lobe of the left lung. Exposure of the tumor showed it to be inoperable because of its extension to the posterior lateral wall of the chest and out over and into the left side of the diaphragm. In the course of the operation, in determining whether or not the tumor was operable, adhesions were separated close to the mediastinum and anterior to the pericardium; furthermore, a small opening was made into the lung in the separation of another adhesion; this latter opening was easily closed with sutures. The long incision between the ribs was closed without drainage.

Five hours after operation emphysema of the face and scrotum appeared, with crepitation along the left lateral wall of the chest. The surgical emphysema increased very rapidly, and soon the patient's face

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Supported by the J. J. and Nettie Mack Foundation.
Received for publication, Feb. 25, 1936.

had swollen beyond recognition. Approximately ten hours after operation, a portion of the wound was reopened, and closed drainage of the left pleural cavity was instituted by the use of a rubber tube. A definite communication between an open bronchus and the left pleural cavity was demonstrated; air was blown out through the tube under water with each expiration. The patient became progressively more dyspneic and the heart action weaker until death occurred twenty-five and a half hours after operation. The patient's death occurred quite suddenly and unexpectedly.

The striking finding at necropsy was a bilateral pneumothorax with complete collapse of both lungs and a generalized subcutaneous and mediastinal emphysema. No actual tear in the mediastinal pleura of the right side could be demonstrated, nor could the bronchial fistula, which surely was the cause of the emphysema, be found.

*Comment.*—It would seem that, in this patient, the contralateral pneumothorax was undoubtedly the immediate cause of death, and although his outlook was hopeless by reason of the inoperable carcinoma, an early postoperative death could have been prevented had we recognized the bilateral nature of the pneumothorax. Because of the complete collapse of the right lung we concluded that there must have been a small rent in both layers of the mediastinal pleura (originating perhaps from a tension pneumothorax in the side operated on), resulting in a free communication between both pleural cavities and consequently a complete collapse of the right lung.

CASE 2.—This patient was a male forty years of age, suffering from a primary carcinoma of the upper lobe of the left lung, with symptoms of six months' duration. The diagnosis was confirmed by biopsy obtained through the bronchoscope. He was given a course of deep roentgenotherapy with considerable subjective and objective improvement. Operation was performed approximately six weeks after the last x-ray treatment. Avertin with gas and oxygen were the anesthetics employed, the gas and oxygen being administered through the ordinary mask. The left lung was exposed through a long incision between the ribs. The upper lobe was found to be indurated and shriveled; the lower lobe was intimately adherent to the upper, so a complete left pneumectomy was elected. This was accomplished by individual double ligation of the vessels and division of the left main bronchus just proximal to the division of the upper lobe. Aside from dense adhesions between the mesial surface of the lung and the pericardium, in the separation of which the pericardium was opened for a distance of 6 cm., the operation was accomplished with comparative ease. The opening in the pericardium was easily closed with interrupted sutures. Following the closure of the incision, the patient was turned on his back (he had previously been on his right side), and suddenly died of cardiac failure. His condition up to that time had been entirely satisfactory.

Necropsy showed the right lung to be entirely collapsed. No communication between the right and the left pleural cavities through a rent in the mediastinum could be demonstrated. There was no bleeding or leakage of air from the pedicle. Although not relevant to this discussion, it is worthy of note that the only metastases present were two small nodules in the left kidney and one in the right. Microscopic examination of the left lung failed to show any cancer cells—the x-rays had destroyed the entire tumor of the lung.

*Comment.*—We are of the opinion that there must have been a small opening made through the mediastinum at the time of operation which permitted air to leak into the right side and collapse the right lung. This could well have occurred during the freeing of the lung from the pericardium, as the adhesions there were sufficiently dense to have caused the surgeon to enter the pericardium. As soon as the patient was turned on his back the anesthetist removed the gas mask and thus there was no means of keeping the right lung expanded, and the heart failed immediately. Had we recognized the exact state of affairs, we are confident that we could have tided the patient over this complication by the continuation of positive pressure in addition to the use of a catheter, connected under water, introduced, between the ribs, into the right side of the thorax.

CASE 3.—A boy ten years of age had bronchiectasis of the lower lobe of the right lung. Preliminary to operation a right closed pneumothorax was produced which collapsed the entire right lung almost completely; the pneumothorax was continued for several days before surgery. Operation was performed Nov. 1, 1935. The patient was anesthetized with avertin and gas and oxygen. The latter was at first administered through an intratracheal catheter. The intratracheal catheter did not function satisfactorily as the patient could not be kept sufficiently relaxed; the anesthetist corrected this by supplying the anesthetic mixture through the mask, leaving the intratracheal catheter in place but covering it with a gas mask. The right pleural cavity was exposed through a long incision in the seventh intercostal space. The right lobe was definitely diseased, while the middle and upper lobes appeared quite normal. The lower lobe was adherent to both the diaphragm and the mediastinum, but separation of these adhesions between hemostats was accomplished fairly easily. The lower lobe having been sufficiently freed, a Roberts-Nelson tourniquet was applied to the pedicle of the lower lobe, and the diseased lobe was excised. The vessels and bronchi were individually ligated, and the closure of the stump was completed by the approximation of the two cuffs of lung tissue and pleura which were left in the pedicle, as is frequently our practice in handling the stump of the pedicle. Just at the completion of closing the pedicle the heart action stopped. Gentle massage of the heart through the

mediastinum (without interruption of the continuity of this structure), in addition to forced inflation of the lungs and the administration of adrenalin intramuscularly, reestablished the heart action. It was noted that any time the positive pressure was discontinued, the lungs expanded poorly and the pulse became weak and irregular. Under forced positive pressure, the operation was successfully completed. A needle was then introduced into the left side of the thorax, and free air was found to be present. A catheter was inserted between the ribs into the left thorax and connected under water. The positive pressure was then discontinued, and the patient was able to carry on with a fairly normal rate and depth of respiration. A moderate amount of air bubbled out through the catheter for the first hour after operation, and then all leakage of air ceased. Twenty-four hours after operation the left catheter was removed from the thorax. The patient recovered completely without further complications except a low-grade empyema on the side operated on. This subsided rapidly after drainage and irrigation with Dakin's solution.

*Comment.*—A contralateral pneumothorax was immediately expected in this case because of the experience with the first two patients, already described. It seems most probable that this complication arose from a small tear through both layers of the mediastinal pleura at the time either of the separation of adhesions or of the closure of the pedicle. I am confident that the immediate increase in positive pressure and, later the removal of the air from the left side of the thorax prevented a fatal termination in this case.

We believe that the type of anesthesia and the manner of its administration are important in these cases. It is our custom first to anesthetize the larynx locally before the administration of the avertin rectally. After the patient is asleep, the intratracheal catheter is inserted through an already anesthetized larynx. This procedure greatly lessens the coughing and straining associated with the use of an intratracheal tube. In the last case, too little time was allowed after the administration of the avertin before the intratracheal catheter was inserted. The result was difficulty in the introduction of the tube and the patient expelled a considerable amount of fluid from his rectum. The operation was begun with the patient taking his anesthesia badly, and we have since made it a rule never to enter the pleural cavity for major surgery unless the patient is under a satisfactory intratracheal anesthesia and therefore breathing normally and quietly, with the necessary surgical relaxation.

## CONCLUSION

Attention is called to the serious complication of contralateral pneumothorax associated with major intrathoracic surgery, which can be easily managed if recognized. Contralateral pneumothorax accounted

for the early postoperative death in two of the cases reported, and would certainly have resulted in the death of the third patient except for our experience with the other two. In all these cases it has been assumed that the contralateral pneumothorax resulted from a communication to the unoperated side through a probable tear of both layers of the mediastinal pleura. Such a tear could not be demonstrated in the two cases that came to necropsy. There is another possible explanation for the occurrence of this complication. If the patient's breathing is labored or if too high a positive pressure is delivered through the anesthetic apparatus, it is conceivable that a contralateral pneumothorax might result from a rupture of one or several alveoli of the lung on the unoperated side. The necessity for satisfactory intratracheal anesthesia in this type of surgery is emphasized particularly from the standpoint of preventing the complication under discussion.

Any change in the patient's respiratory action, associated with failing of the pulse, should immediately suggest contralateral pneumothorax. Increased positive pressure and an outlet for air (under water) into the pleural cavity on the unoperated side is the suggested treatment of choice.

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# NEGATIVE SPUTUM*

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IT IS customary in reports of results following collapse therapy to include the percentage of patients whose sputum became negative for tubercle bacilli. In five leading American journals in which such reports are most likely to be published we found between January, 1933, and July, 1935, about thirty papers that mention as one of the criteria of therapeutic results "sputum became negative." The vast majority of these papers do not contain any mention upon what criteria a sputum is considered negative. One author says that when a concentrated specimen does not reveal tubercle bacilli it is deemed negative; another one refers to negative sputum "as qualified by the N. T. A." The rest of the authors simply do not say anything on the question. Essentially similar omissions are found in textbooks and in the European literature.

We do not know anything about the intricacies of thoracic surgery, but we have accumulated some pertinent data on sputum examinations and on critical methodology. On the basis of this experience we feel justified to say that the unqualified term "negative sputum" has just as little meaning as the term "normal renal" or "normal cardiac function" without stating fully by what observations or tests normality was assumed to exist. Since negative sputum is supposed to be of great moment from the point of view of public health, and since it is undoubtedly of greatest importance in the diagnosis of a healed cavity, it seemed of fundamental interest to us to gain at least an approximate idea of the relative reliability of the various criteria for negative sputum. We have found in previous studies that in the routine run of newly admitted patients to a tuberculosis sanatorium, about 95 per cent of all positive sputums are found so by direct smears. Therefore in order to evaluate different methods for the demonstration of tubercle bacilli in paucibacillary sputum it becomes necessary to examine selected groups of patients.

We have tabulated in Table I a total of 239 specimens from patients who, for reasons of clinical or roentgenologic findings, of history or symptomatology, were suspected of having tuberculosis and in whose specimens tubercle bacilli could not be found in repeated direct smears. It is evident that these specimens represent "difficult specimens," since all those in which tubercle bacilli were found by direct smears, are excluded.

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Received for publication, February 8, 1936.

These examinations were done in three different institutions: the Maybury Sanatorium, Northville, Michigan; the Desert Sanatorium, Tucson, Arizona; and the Southern Pacific Hospital, Tucson, Arizona. The material in Table I is, therefore, far from homogeneous, but it is probably representative enough to answer—in an approximative way—what percentage of specimens, negative on repeated direct smears, are found positive by concentration, by cultural methods and by guinea pig inoculation. These 239 specimens came from patients with relatively early lesions and from patients who had undergone treatment of different kinds; in other words, the specimens were either of differential-diagnostic or of prognostic interest. The number of specimens and

TABLE I

COMPARATIVE RESULTS OF DIFFERENT METHODS FOR THE DEMONSTRATION OF TUBERCLE BACILLI IN 239 SPECIMENS FROM TUBERCULOSIS PATIENTS, ALL "NEGATIVE" ON DIRECT SMEARS

| NUMBER OF SPECIMENS | POSITIVE ON CONCENTRATION | | POSITIVE ON CULTURE | | POSITIVE ON INOCULATION | | POSITIVE BY ANY METHOD | |
|---|---|---|---|---|---|---|---|---|
| | NO. | PER CENT | NO. | PER CENT | NO. | PER CENT | NO. | PER CENT |
| 239 | 25 | 9.6 | 133 | 56.5 | 185 | 77.4 | 239 | 100.0 |

the number of patients do not coincide, since several separate specimens of the same patients are included. It is impossible on the basis of our available records to state the accurate number of patients; but since not many repeat specimens are included, we are safe in assuming that Table I represents specimens from nearly 200 individual patients. This table compares the efficiency of the various methods in percentages of the total number of tuberculosis specimens after the exclusion of the overwhelming majority of specimens that were found to be positive on direct smears.

In a previous publication[1] we reported 92 patients whose etiologic diagnoses had been previously established bacteriologically, but who for at least two months had had negative direct smears. Table II summarizes the results.

TABLE II

COMPARATIVE RESULTS OF CULTURE AND ANIMAL INOCULATION OF 92 SPECIMENS, "NEGATIVE" ON REPEATED SMEARS AND CONCENTRATIONS, FROM 92 PATIENTS IN WHOM TUBERCLE BACILLI HAD BEEN DEMONSTRATED PREVIOUSLY

| NUMBER OF SPECIMENS | POSITIVE ON CULTURE | POSITIVE ON INOCULATION | POSITIVE BY ANY METHOD |
|---|---|---|---|
| 92 | 70.6% | 93.5% | 100.0% |

In order to apply such findings directly to patients following collapse treatment, we started to inoculate all "negative" sputums of such patients into guinea pigs. On account of external circumstances, this series had to be interrupted prematurely, and for technical reasons

cultures could not be made. Twenty-one patients were available; they had had at least 8 and as many as 77 direct smears and concentrations with negative results; only one had 2, and one had 4 smears and concentrations. The interval between the collapse measure and the animal inoculation varied between six and seventeen months. Of these 21 patients 10 were shown by inoculation to have a positive sputum.

It should be added here that sputum examination should not be done according to a rigid routine, but that it should be adapted to the particular condition of each case. Patients whose sputums consist obviously of a large part of saliva and nasal secretion should be given two sputum containers; they should be instructed to use one only for true sputum, the other for all secretions originating apparently from above the larynx. In patients with scant amounts of sputum, the sputum should be collected for a number of days or for a whole week, if necessary. Certain patients have only occasionally some expectoration; their sputum should be collected at the most opportune time in the judgment of the patient himself and not at a rigidly fixed date. In some patients who report that they have no sputum, a careful explanation of the mechanism of expectoration will produce ample specimens; in others laryngeal smears or gastric lavage will yield results. (A detailed discussion of the technics for the demonstration of tubercle bacilli has been published previously.[2]) Although it does not belong strictly to the topic under discussion, it should be mentioned that the considerable discrepancy between the results of cultures and of animal inoculations in our tables are not representative of our present work. We have included in our tables material collected during the last eight years. In recent years, cultural methods have been sufficiently improved to bring their efficiency very closely up to the level of that of guinea pig inoculations.

## DISCUSSION

The material that we have presented contains relatively few sputums from patients who have been treated apparently successfully by collapse procedures. We are, therefore, not in a position to state in what percentage of such patients apparently negative sputum can be demonstrated to contain tubercle bacilli when all bacteriologic methods are applied. It seems justified, however, to emphasize the fact, as clearly demonstrated by our material, that the various methods mentioned are of a very different degree of efficiency. It seems permissible to assume that the same applies to sputums from patients treated by collapse, although further studies must determine the actual numerical discrepancies in results according to the various methods. Our small series of patients under collapse would indicate that animal inoculations demonstrate bacilli in roughly half of the sputums that were found to be negative by frequently repeated smears and concentrations.

It should be clearly understood that the purpose of this report is not an evaluation of collapse therapy in terms of positive and negative

sputum, but to point out the necessity of qualifying the term "negative sputum" by stating explicitly what methods were used for the search of tubercle bacilli. Without this, statistics on surgical results, or for that matter any results, are unreliable and totally incomparable. It is not our intention to suggest a definite bacteriologic routine, but to request that the specific methods used in a given series be mentioned. The figures that we have presented will probably give a rough idea of the reliability of the various methods. The chief argument against using routinely the most complete and accurate methods is that "it is too complicated and expensive for our set-up." But it is not easily understood how a hospital can afford to get and maintain the personnel, the space, the apparatus and the instruments basically necessary for thoracic surgery, and cannot afford to maintain a laboratory unit, infinitely less expensive, that would provide one of the most important controls of the surgical work.

This leads to another argument: Is there, for any practical purposes, a significant difference between a patient whose sputum is really negative and a patient who expectorates so few bacilli that only guinea pig inoculation will demonstrate them? On the basis of our own material and according to the data available in the literature, this question cannot be answered. To change a patient with copious sputum, teeming with bacilli, into one with traces of sputum with very few bacilli, is undoubtedly a significant therapeutic result. But this is not the question that we posed; to answer it, it would be necessary to follow clinically for years, two series of patients following collapse therapy, one bacillus-free on the basis of the most complete sputum examination, and one with but few bacilli, demonstrable only by culture or inoculation. We do not know of any such studies.

However, so long as it happens in a certain percentage of (unqualified) negative-sputum cases that years after well-being and after collapse therapy, unexpected breakdowns and fresh infiltrations occur, so long may one suspect that these fateful episodes occur more frequently in patients who—in spite of their clinical improvement—continue to expectorate a few bacilli. The term "bacillary carriers," frequently suggested for this group, is totally misleading. Also, it still remains to be determined whether or not a large proportion of such patients turn negative, not with the speed expected from surgical interference, but with the slowness of natural healing processes after proper mechanical conditions for healing have been established by appropriate surgical procedures. What should be done with these paucibacillary patients? The answer belongs obviously in the province of the clinician and not in that of the laboratory worker. But it requires the close cooperation of the two to recognize this problematical group of patients.

This report should in no way be interpreted as a criticism against collapse therapy. It is presented solely in order to point out the desirability of a stricter and more uniform evaluation of therapeutic results.

SUMMARY

1. On the basis of a numerical comparison of various methods for the demonstration of tubercle bacilli, it is shown that the unqualified term "negative sputum" is practically meaningless.

2. Many patients whose sputum is found negative on repeated direct smears and concentrations expectorate bacilli that can be demonstrated by cultural methods and guinea pig inoculation, by the use of laryngeal smears and gastric lavage, and by appropriate methods of sputum collection.

3. Following collapse therapy, and particularly following thoracoplasties, the roentgenologic evidence of healed cavities is often misleading and always inconclusive unless confirmed by the absence of sputum or the absence of tubercle bacilli according to the strictest tests.

4. It is urged not to use the term "negative sputum" without stating specifically the criteria that were used to establish the absence of tubercle bacilli.

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# CAVITY CLOSURE BY COMBINED PNEUMOTHORAX AND PHRENIC NERVE INTERRUPTION

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THE complementary use of permanent or temporary phrenic nerve interruption and artificial pneumothorax is not new to phthisiotherapists. The complete or partial failure of one of these collapse therapy methods is often deemed sufficient reason to add the other in the hope of procuring complete success. In fact, the addition of phrenic exeresis to every artificial pneumothorax has been advocated[1] on the thesis that every successful pneumothorax case should have the advantage of hemidiaphragmatic paralysis when the time for lung reexpansion arrives, and every incompletely successful pneumothorax case may become successful with the added factor of hemidiaphragmatic paralysis and rise. Probably the indication most commonly accepted for the addition of phrenic nerve interruption to an existing pneumothorax in pulmonary tuberculosis, is the persistence of an open cavity because of pleural adherence. Most authors who have discussed the subject are agreed that diaphragmatic paralysis and rise are the mechanical factors resulting in increased immobilization, relaxation and compression of the lung.[2, 3, 4] Slavin, however, in analyzing the mechanics involved, differs in the value assigned to diaphragmatic rise.[5]

If the general indications for the addition of phrenic exeresis to all pneumothorax cases, suggested by Pollock and Forsee,[1] are widely accepted, there is no need for further study or discussion of more specific indications, or, as these authors themselves list, "more conservative indications." However, if for no other reason than to preclude useless surgery and to preserve as much normal physiologic function as possible, I have sought to verify indications mentioned by these and other authors and further to delineate criteria for combining these two collapse methods in the attempt to close tuberculous cavities. The following analysis of 78 cases in which this combination of methods was used by no means represents the total number in which phrenic nerve interruption was used to complement an artificial pneumothorax, or vice versa; rather, it includes cavity cases only in which the two methods were technically established coincidentally; e.g., an abandoned unsatisfactory pneumothorax for which phrenic nerve interruption was substituted would not be included, or an established pneumothorax case in which phrenic nerve surgery was performed but failed to show dia-

Received for publication, September 19, 1935.

phragmatic paralysis would be excluded. Roentgenologic evidence of the closure of cavities was used as the sole criterion of success. It is recognized that other laboratory and clinical evidence may in some cases belie roentgenologic evidence of cavity closure; but it is felt that in the vast majority of cases, such x-ray evidence parallels other evidence of success in cavity closure, whether induced by bed rest or by some method of lung collapse. Furthermore, the evidence of cavity closure presented here is not given as evidence of a cure and permanent closure of the cavities; a later analysis will be necessary to present such evidence. This analysis is presented from the standpoint of procedure, rather than from the standpoint of end-results.

Thus, among the 78 cases, 49 are classed as successes and 29, as failures. Pneumothorax was first established in 55 cases and was continued after diaphragmatic paralysis was obtained; of these, 35 were successes and 20, failures. Phrenic nerve interruption was performed first, and pneumothorax later established, in 23 cases (14 successes, 9 failures). Of course, the assessment of the value of the diaphragmatic paralysis in the latter group is much less possible than in the former.

There were 50 left-sided cases (30 successes, 20 failures), and 28 right-sided cases (19 successes, 9 failures). The range in age of the 44 female patients (27 successes, 17 failures) and 34 male patients (22 successes, 12 failures), was from 12 to 53 years, with 49 patients between 21 and 35 years. Among the successful cases, 2 were found with no rise of diaphragm noted; one with descent of the diaphragm as pneumothorax was continued; and 6 cases in which diaphragm level was hidden by fluid. Of the unsuccessful cases, 4 revealed no rise of the diaphragm. The average mensurable rise of the diaphragmatic leaf in the successful cases was 4.5 cm., the maximum, 10 cm.; that in the unsuccessful cases 3.3 cm., with a maximum of 7 cm. I agree with the contention that the height of rise of the diaphragm is an important factor in results obtained. Phrenic nerve surgery was performed in 2 cases after unsuccessful attempts at establishing pneumothorax had been made, and then subsequent pneumothorax attempts were successful. Phrenic nerve crushing (temporary interruption) was performed in 6 of the unsuccessful cases and in 21 of the successful cases; one of these was followed by exeresis because of early return of diaphragmatic motion. Of those with exereses performed, 28 were successes and 23, failures. No case was under observation sufficiently long to allow purposeful reexpansion of the lung.

More detailed study of the unsuccessful cases, in an attempt to learn the causes of failure, has suggested these observations:

I. Too long a delay between the evident failure of pneumothorax in cavity closure and the addition of phrenic nerve surgery is not only a

loss of time for the patient but may jeopardize chances for success; this is most often due to gradual loss of pneumothorax space by pleural symphysis or to fluid formation with resultant anchoring of the hemidiaphragm. A trial period of two to six months in most cases, with or without evident adhesions holding the cavity open, is sufficiently long to determine whether the cavity is likely to close under pneumothorax alone. (See Fig. 1.)

II. If pneumothorax reveals that the wall of a large upper lung cavity is *diffusely* adherent to the chest cage, phrenic nerve surgery aiming at cavity closure will be unsuccessful, as has been previously noted.[5] Diminution in the size of such cavity may be expected in some cases, and the phrenic nerve surgery may thus be justified as a preliminary to thoracoplasty or for indirect help to the contralateral lung. But more often this type of cavity enlarges or remains unaffected by pneumothorax. Failure of pneumothorax in these cases indicates adoption

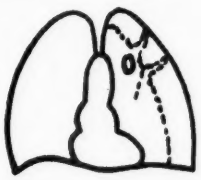

Fig. 1.

Fig. 2.

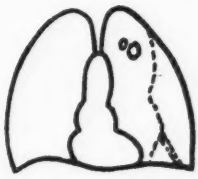

Fig. 3.

Fig. 1.—No. 4271. Cavity, 3 × 4 cm., at first left interspace, on admission. Pneumothorax induced August, 1929. String adhesions preventing cavity closure evident in film of February, 1930, as represented in Fig. 1. Positive pressures used in attempt to stretch adhesions, fluid formation following. Left phrenicectomy performed in June, 1931; should have been performed about February, 1930. Thoracoplasty required finally to close cavity.

Fig. 2.—No. 4203. Huge cavity, left upper, increased in size under pneumothorax induced April, 1930, as represented in Fig. 2. Wall of cavity diffusely adherent. Left phrenicectomy in September, 1931, with some diminution in cavity size, but not complete closure. Thoracoplasty necessary for closure.

Fig. 3.—No. 3271. Subclavicular cavities, left, with lung parenchyma between cavity walls and diffusely adherent pleurae. Pneumothorax induced November, 1929, with no notable effect on cavities, as shown in Fig. 3. Left phrenicectomy in July, 1930. Cavities still patent on x-ray examination four years later, although pneumothorax continued until obliterative pleuritis prevented refills. Contrast with Fig. 6.

of thoracoplasty plans if not otherwise contraindicated. Of our 29 unsuccessful cases, 16 were of this type. (See Fig. 2.)

III. An apical cavity with parenchymal tissue between its walls and the area of diffuse pleural symphysis, and with no collapse effect evident by a pneumothorax pocket delimited to the lower part of the lung, *may* be unaffected by a complementary diaphragmatic paralysis and rise. (See Fig. 3, and contrast this observation with II under the discussion of successful cases.)

IV. The use of continued positive pressures of pneumothorax in an effort to stretch or loosen adhesions and close cavities is fraught with the danger of fluid formation, in addition to the danger of superimposed spontaneous pneumothorax and possible empyema. A better pro-

cedure might be to perform phrenic nerve interruption before resorting to the trial of positive pressures. Slightly positive pressures do not always depress a paralyzed diaphragm. Of our unsuccessful cases, 11 developed fluid after positive pressures were applied; 8 successful cases developed fluid after positive pressures, and in 3 of these the fluid seemed to be of some aid in closing diffusely adherent cavities. (The last 3 cases constitute exceptions to observation II above; the possibility of a dissecting action by the fluid may account for this apparent effect.) It should be noted that 8 successful cases had positive pressures used without complicating effusion. It is not my contention that positive pressures alone are responsible for fluid formation, but in the presence of adhesions continued positive pressures are liable to be followed by effusion. In this series 6 cases without record of positive pressures developed effusions (5 successes and 1 failure). (See Fig. 1.)

More detailed study of the successful cases suggests the following observations:

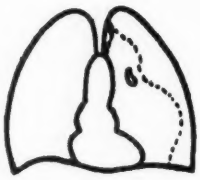

Fig. 4.

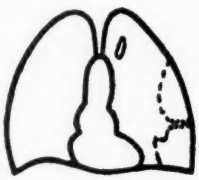

Fig. 5.

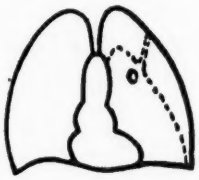

Fig. 6.

Fig. 4.—No. 5500. Cavity at second rib, left, with no evident adhesions at cavity level (string adhesion in apex), as represented in Fig. 4. Pneumothorax induced November, 1932. Left phrenicectomy performed December, 1933; cavity closed on x-ray examination of February, 1934.

Fig. 5.—No. 6735. Cavity, 2.5 × 3 cm., left upper, on admission. Cavity decreased in size but persisting, long and narrow, under pneumothorax induced September, 1933, as represented in Fig. 5. Lung parenchyma between cavity wall and diffusely adherent pleurae. Left phrenicectomy in April, 1934, with cavity closure resulting.

Fig. 6.—No. 5752. Bilocular cavity, 2.5 × 3.5 cm., left upper, on admission. Pneumothorax induced in July, 1932. Cord adhesion visible in second interspace, apparently feasible for intrapleural pneumonolysis, as represented in Fig. 6. Phrenicectomy November, 1933; cavities closed January, 1934.

I. If a cavity persists under pneumothorax and if failure to close is not accounted for by evident adhesions directly at the level of the cavity, phrenic nerve interruption as a complementary measure is in order, and that before too long a trial under pneumothorax alone. (See Fig. 4.)

II. Cavities in the apical portion of the lung, with lung parenchyma between its walls and diffusely adherent pleural surfaces (i.e., not the cavity walls themselves diffusely adherent) and such cavities not completely obliterated by pneumothorax, *may* be closed by complementary phrenic nerve interruption. (See Fig. 5, and contrast with III under failures.)

III. Cavities apparently held open by cord or stringlike adhesions, the so-called suspended cavity, and possibly presenting good indications for

intrapleural pneumonolysis, may be closed by the addition of phrenic nerve interruption to the pneumothorax. (See Fig. 6.)

IV. Just as phrenic nerve surgery proves a valuable complement to pneumothorax in many cases, so does pneumothorax prove a valuable adjunct to incompletely successful phrenic nerve interruption in attempts at cavity closure; i.e., a case may have been adjudged suitable for phrenic nerve surgery as the preferable method, and this having failed, an added pneumothorax may bring success. (See Fig. 7.)

Some observations, less well established in this series, are here mentioned:

I. A cavity unclosed by pneumothorax alone may or may not be closed by a complementary interruption of the phrenic nerve in the presence of a mediastinal hernia. If the cavity is opposite the level of the apparent bulge of the mediastinum, it will not be closed by the added diaphragmatic paralysis and rise. If the cavity is at a level higher than that of the hernia, it may be closed by adding phrenic nerve surgery.

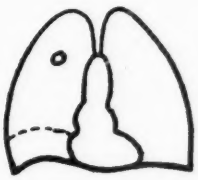

Fig. 7.—No. 5917. Cavity right midlung, 4 × 5.5 cm., and cavity 2 × 3 cm., at second rib on left, on admission. Right phrenicectomy February, 1932, with marked reduction in size of cavity on right resulting, and apparent obliteration of cavity on left, as represented in Fig. 7. Right pneumothorax initiated March, 1933; cavity, right, closed October, 1933, in spite of fact that free collapse by pneumothorax was impeded by diffuse apical adherence.

II. If the phrenic nerve interruption has been a temporary one (crushing of the main trunk and resection of accessory branches), and if the combined methods have proved successful, frequent observations for resumption of function of the hemidiaphragm must be made, and the main-trunk crush repeated or an exeresis performed to prolong the opportunity for firm healing at the site of the closed cavity.

III. Unsuccessful attempts to establish pneumothorax, followed by phrenic nerve interruption, may rarely be followed by successful attempts to establish pneumothorax after paralysis and rise of the diaphragm has occurred. Unimpeded collapse is, however, rarely obtained in such cases.

## CONCLUSIONS

An analysis of 49 successful and 29 unsuccessful cases of tuberculous cavity closure by coincident and complementary artificial pneumothorax and phrenic nerve interruption, indicates that the combined methods have a definite value in tuberculosis therapy.

Careful study of projected cases may enable more exact prognosis and may eliminate unnecessary surgery.

Temporary interruption of the phrenic nerve should be the general rule, thus giving the combined methods an ample trial; if cavity closure results, the temporary interruption may be repeated or the interruption may be made permanent; if the cavity fails to close, the diaphragmatic function will return, and further surgical procedures may be considered without the possible embarrassment of a hemidiaphragmatic paralysis and rise.

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# PHRENIC EXERESIS AT THE TERMINATION OF PNEUMOTHORAX THERAPY*

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SEVERAL types of compressed lungs present themselves at the end-stage of pneumothorax treatment, varying from complete compression of the whole lung to only a small localized pneumothorax, and all degrees and contours of collapsed lungs between these two extremes. These different types are the result of the varying degrees of compression used by individual workers as well as the varying amounts of tissue destruction prior to the initiation of pneumothorax therapy. The smaller the pathologic involvement before initiation of pneumothorax and the less compression applied throughout the treatment, the sooner will reexpansion take place at the termination of pneumothorax and the more respiratory function will be regained by the expanded lung.[1] If the lung architecture, however, was almost entirely destroyed by caseation and fibrosis and was kept completely compressed throughout the treatment, very little functional recuperation and reexpansion can be expected. Patients with such a compressed lung may be practically symptomless while receiving pneumothorax insufflations, but after the termination of the treatment a new train of symptoms often develops as a result of change in the intrathoracic equilibrium which may need surgical intervention.

The empty pleural space left by the compressed and contracted lung tends to fill in gradually by a retraction of many of its adjacent structures, the most important of which are the mediastinum and its contents. A marked deviation of the mediastinum frequently eventuates in shortness of breath, tachycardia, and pain in the chest. Certain patients often complain of a subjective consciousness of the heart beat or peculiar impacts against the chest wall, and breathlessness on exertion. Constitutional symptoms are rarely present, and the entire syndrome is no doubt the result of a disturbance in the cardiocirculatory system caused by the extreme displacement and distortion of the mediastinal structures. A refill with large amounts of air invariably relieves the symptoms. This means a continuation of pneumothorax treatment indefinitely. While certain patients have no objection to continuing refills, others prefer a surgical operation that would help terminate the repeated treatments. The question then arises, which procedure is the

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Received for publication February 24, 1936.

least disturbing and the most effective in preventing a deflection of the mediastinum and its entailing symptoms? We find phrenic exeresis to be the most logical procedure.

A brief discussion of the means adopted by the body to compensate for the loss of lung volume is pertinent in order to explain the rationale of phrenic avulsion in these cases.

## MECHANISM OF COMPENSATION FOR THE LOSS OF LUNG VOLUME AT TERMINATION OF PNEUMOTHORAX

Many factors enter into the mechanism of compensation for loss of lung volume, the most important ones are: (a) retraction of the chest wall, (b) elevation of the diaphragm, (c) shifting of the mediastinum, (d) development of vicarious emphysema, (e) dilatation of the bronchi. The caving in of the chest wall is the slowest process, because of the resistance offered by the rigid bony framework of the thorax; the up-

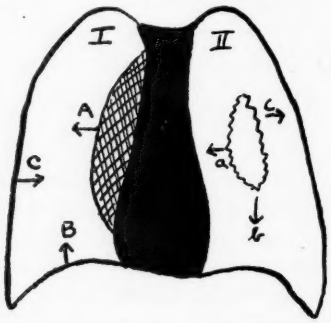


Fig. 1.—Diagram showing the mechanism of compensation for loss of lung volume. *I*, Arrows indicate retracting forces of pneumothorax side in order of their diminishing intensity; *A*, retraction of mediastinum; *B*, pulling up of diaphragm; *C*, depression of the chest wall. *II*, Degrees of expansion of contralateral emphysematous lung toward various directions in their decreasing order: *a*, mediastinum; *b*, diaphragm; *c*, thoracic wall. Obviously the deviation of the mediastinum to the treated hemithorax is a result of the two component forces *A* and *a*, i.e., the traction of the diseased lung plus the expansion of the contralateral lung.

ward deflection of the diaphragm is inhibited by its constant active respiratory movements; the mediastinum is the first to deviate to the affected side, the rate and extent of the deviation depending upon the degree of its flexibility.

The displacement of the mediastinum to the treated side is further intensified by the overdistention of the contralateral lung which, as a rule, develops marked compensatory emphysema. The expansion of the emphysematous lung is not equal in all directions: the rigid thoracic wall yields very slowly to the expansive volume of the lung; the intra-abdominal tension to which the diaphragm is subjected offers a certain resistance to its downward displacement; and most of the expansion of the emphysematous lung is toward the least resisting wall, namely the

mediastinum. The deviation of the mediastinum is thus the result of two forces acting in the same direction, that is the *pull* of the treated cicatrizing lung on one side and the *push* of the vicariously emphysematous lung on the other side. The diagram in Fig. 1 saliently illustrates these points.

Bronchial dilatation is a late occurrence in these cases and may manifest itself years after the termination of the treatment, though some-

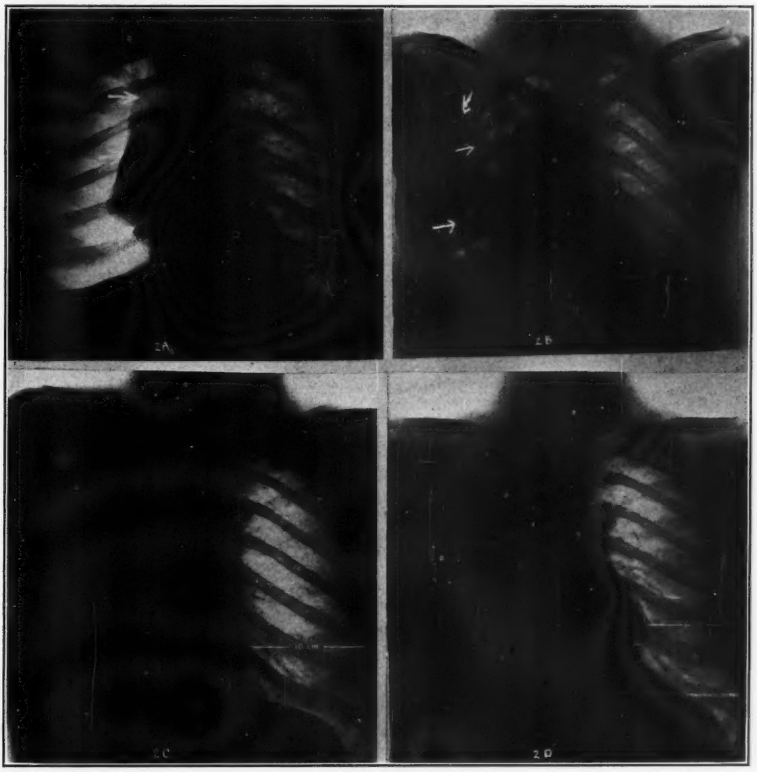

Fig. 2.—*A*, Roentgenogram of a case of right pneumothorax of the compressive type shows the lung volume reduced to a minimum. *B*, Pneumothorax about to be terminated. Note the retraction of the mediastinum to the right. *C*, Roentgenogram of the same patient a few weeks later discloses an extreme dextrocardia and retraction of the mediastinal structures to the right. *D*, Same patient after phrenic exeresis; the right hemidiaphragm is markedly elevated replacing the heart to the left.

times it takes place very early. This type of bronchiectasis is brought about by the irregular traction of the sclerotic parenchyma pulling on the bronchial walls and distorting them. The respiratory strain and stress to which these weakened bronchi are subjected gradually increase the dilatation.

There is a close interrelationship between all these factors of compensation, and an increased action of one causes a proportionate decrease of the others. Thus a depression of the chest wall on the affected hemithorax will reduce the size of the pleural cavity, and consequently less retraction of the mediastinal structure will follow. Or the upward displacement of a paralyzed hemidiaphragm into the treated side will decrease or prevent altogether a shifting of the mediastinum to the same side. It must be borne in mind, however, that while phrenic nerve avulsion will cause paralysis of the hemidiaphragm, the extent of its elevation into the chest will depend mostly on the difference between the intrapleural and the intraabdominal pressure, and above all on the presence or absence of pleuritic adhesions.

## CLINICAL RESULTS OF PHRENICECTOMY AT END-STAGES OF PNEUMOTHORAX

All the patients who manifested symptoms caused by the displacement and the distortion of the mediastinal structures were relieved by the phrenic avulsion on

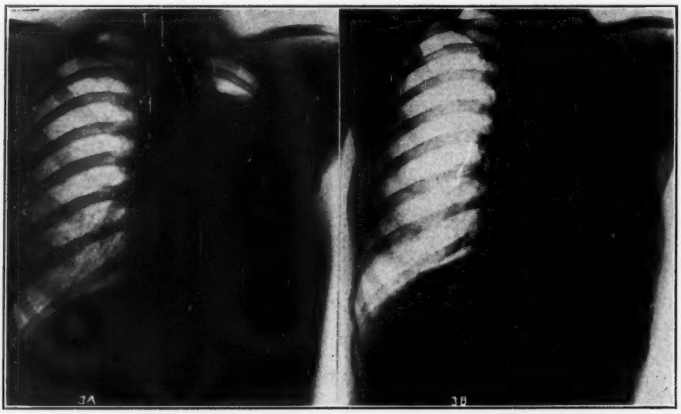

Fig. 3.—*A*, Narrowing of entire left hemithorax with marked retraction of the heart to the left; effusion, and small localized pneumothorax at the apex. *B*, Roentgenogram of the same patient after phrenic avulsion shows the left hemidiaphragm elevated only slightly with no anatomic replacement of the heart, but widening of the upper half of the hemithorax.

the affected side, but the ultimate therapeutic effect as well as the anatomic changes in the thoracic cavity showed decided variations. The following cases in which phrenic exeresis was performed with the purpose of preventing or relieving mediastinal shifting are representative of three different groups with varying therapeutic results.

Fig. 2 *A*, a roentgenogram of a patient treated with compressive pneumothorax shows the volume of the right lung reduced to a minimum, with an apparently stable mediastinum. The patient has been receiving pneumothorax treatment for about three and one-half years. She was symptomless for more than two years and then wished to have the treatments discontinued. The intervals of treatment were then lengthened and the amounts of air at each refill decreased.

Fig. 2 *B* is a roentgenogram of the same patient about three months later. The compressed lung is reexpanded, but its volume is too small to fill the pleural space

of the right hemithorax; the mediastinum appears to place a major rôle in the mechanism of compensation revealing a marked deflection to the right side.

Fig. 2 *C* and *D* are roentgenograms of the same patient, before and after phrenic exeresis, respectively. Fig. 2 *C* shows an extreme retraction of the mediastinum to the right with an almost dextrocardia. The patient complained of dyspnea and palpitation upon exertion, tightness in the right side of the chest and substernal pain. There was no cough or expectoration. On auscultation the

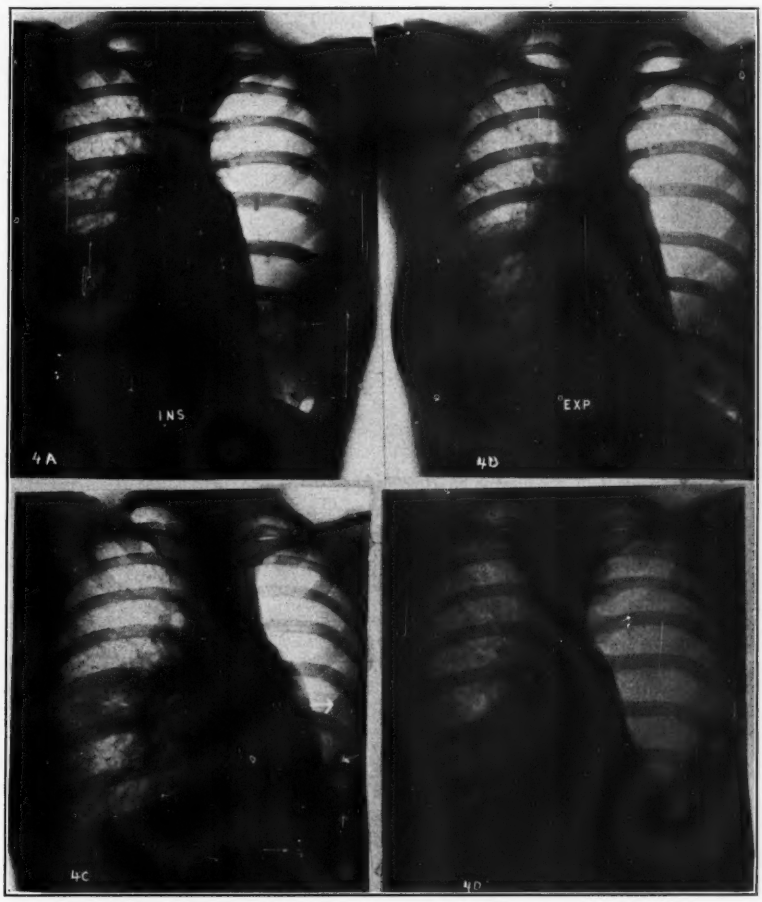


Fig. 4.—*A* and *B*, Roentgenograms in inspiration and expiration respectively, show complete compression of the left lung and an apparently stable mediastinum with very little to-and-fro movements. *C*, Roentgenogram of same patient taken eight weeks later reveals a marked retraction of the mediastinum to the left side and many pleurodiaphragmatic adhesions. *D*, X-ray picture taken after phrenic exeresis exhibits only slight rise of the hemidiaphragm (a small amount of air once in eight to ten weeks is now sufficient to prevent mediastinal retraction).

apex beat was heard best at the right margin of the sternum. Tachycardia was marked. The pulse rate varied from 100 to 135 depending upon her activity. Fig. 2 *D*, the roentgenogram of the same patient after the right phrenic nerve was

avulsed, discloses a markedly elevated right hemidiaphragm replacing the heart to the left. The symptoms previously described had completely disappeared.

This case represents the group which has gained most by the operation; not only were the symptoms relieved but the replacement of the heart and mediastinum was almost within physiologic limits. It is not always possible, however, to obtain an anatomic readjustment of the mediastinum, though symptomatic relief will follow the operation, as represented by our second group.

Fig. 3 *A* shows a marked retraction of the mediastinal structures to the left side with probable thickening of the pleura and a small effusion. The fluid level is at about the first intercostal space, and a small localized pneumothorax is visible at the apex. The patient related that she was under pneumothorax treatment for about four years but did not receive any refills for the last six months. She complained of dyspnea on exertion and an annoying sensation of constantly hearing and feeling her heart beat. Physical examination indicated a rather small quantity of fluid, and a roentgenographic examination in the right lateral position disclosed a free shifting level. About 300 c.c. of fluid were aspirated before phrenic avulsion.

Fig. 3 *B* is an x-ray film of the same patient after phrenic avulsion. It reveals only a slight elevation of the left diaphragm with very little change in the deflection of the mediastinum. Surprisingly enough, the patient no longer complained of a consciousness of the heart beat, and physical examination failed to disclose the pulsation of the apex beat which was formerly visible and quite distinct in the left midaxillary region. It is of interest to note, also, the widening of the upper half of the hemithorax and the replacement of the trachea toward the midline (the edges of the trachea in this instance were artificially accentuated for the purpose of illustration).

From the mechanical viewpoint this case is not entirely successful, since not enough replacement of the mediastinal structures followed the operation. The mere relaxation of the paralyzed hemidiaphragm, however, released the drag on the pleuropericardial adhesions which in turn brought about a cessation of the symptoms.

Basal adhesions may hinder a high rise of the diaphragm into the chest even in the presence of a free pleural space. Pneumothorax treatment will have to be continued in such cases if the mediastinal retraction is to be prevented. The paralysis of the hemidiaphragm, however, greatly lengthens the time intervals between insufflations, sometimes as long as ten to twelve weeks, as illustrated in the following cases.

Fig. 4 *A* and *B*, x-ray pictures of the same patient taken in inspiration and expiration, respectively, show a complete compression of the left lung, and an apparently stable mediastinum inasmuch as very little to-and-fro motion is noted with the respiratory phases. The patient received about 350 c.c. of air at intervals of fourteen to sixteen days, and had been practically symptomless for one year. It was decided to extend the intervals of insufflation with a view toward terminating the pneumothorax therapy. Fig. 4 *C*, an x-ray picture of the same patient taken eight weeks later, shows a marked retraction of the mediastinum to the left side. Injection of contrast medium into the compressed lung revealed an irregular bronchial dilatation. The patient also complained of a dry cough and a jerky pain at the left base, brought on by exertion. Phrenic exeresis was performed. Fig. 4 *D*, an x-ray picture taken a few weeks after the operation, shows only a slight elevation of the diaphragm into the chest. The cough and pain have disappeared completely due undoubtedly to the relaxation of the pleurodiaphragmatic adhesion. The mediastinal retraction was not altogether prevented by the phrenic avulsion,

and pneumothorax had to be continued. Instead of giving treatment every two or three weeks, however, it was now necessary to reinsufflate the pleural cavity only once in every ten or twelve weeks.

## DISCUSSION

Phrenic exeresis is gaining its place as a supplementary operation to artificial pneumothorax, but the recommendation of Alexander,[2] Zadek[3] and others to apply this procedure in every case of artificial pneumothorax indiscriminately is entirely unjustified.* Not every lung treated with artificial pneumothorax becomes wholly shrunken and cicatrized. By far the great majority of lungs successfully treated with hypotensive pneumothorax reexpand almost completely, entailing only a very little retraction of the adjacent structures. This is particularly true in cases of the selective type of pneumothorax which immobilizes the diseased part only and curtails very little of the function of the healthy portion of the treated lung; this functioning portion undergoes a compensatory emphysema, expands gradually but persistently, fills the space left by the healed and contracted portion, and eventuates in almost complete recuperation of the respiratory capacity.[4] To paralyze the hemidiaphragm in such cases is not only unwise but harmful, inasmuch as it may cause a permanent diminution in the vital capacity. It is different, however, in cases of advanced pulmonary lesions with extensive anatomic destruction and thickened pleura. Such lungs are usually treated with a compressive type of pneumothorax for a long time, and the contracted cicatrized lung fails to reexpand at the termination of the treatment, leaving an empty pleural space which eventually is filled by the retraction of the adjacent structures, mostly those of the mediastinum.

To prevent an extreme deviation of the mediastinum one of four methods of procedure may be pursued: (a) maintain a high-tension pneumothorax, (b) establish an oleothorax, (c) perform thoracoplasty, or (d) phrenic exeresis. Those who wish to continue artificial pneumothorax may do so with the understanding that treatments will have to be given for the remainder of their lives. We do not think oleothorax advisable in such cases, for this procedure would require just as much medical attention as pneumothorax treatment, if not more, and will frequently eventuate in a retraction of the mediastinum. A thoracoplasty would obliterate the pleural cavity, but it is too extensive an operation for this purpose, leaving the patient with an unnecessary deformity. A timely application of phrenic avulsion usually assures good results with least disturbance to the patient.

The problem that confronts us is whether to perform a phrenic avulsion in this type of case before changes occur which militate against the patient's well-being, or whether to wait until these changes mani-

*EDITOR'S NOTE.—In a later article Nehil and Alexander (J. THORACIC SURG. 2: 549, 1933) indicate that the earlier recommendation of Alexander has been modified.

fest themselves. We find that the best time to operate is when there is a free pleural space which allows the denervated hemidiaphragm to be definitely elevated thereby preventing extreme retraction of the mediastinum with its concomitant symptoms. Fig. 2*C* and *D* are very illustrative of this group of cases, in which phrenic avulsion proved to be most effective both in mechanical and in therapeutic results. After retraction of the mediastinum has taken place with formation of pleural adhesions, the mechanical effects of phrenic avulsion are greatly hindered, but its therapeutic value is still definite particularly in alleviating tachycardia and dyspnea due to pleuropericardial adhesions.[5] Fig. 3 *A* and *B* are representative of the second group of our cases in which the mere relaxation of the hemidiaphragm brought about complete symptomatic relief.

Even if the rise of the paralyzed diaphragm into the pneumothorax cavity is not marked, it prevents the rapid shifting of the mediastinum and lengthens the intervals of reinsufflation by several weeks, a phenomenon which was also observed by Zadek,[3] Dumarest,[6] and others. These are the cases of the third groups of our series, in which phrenic avulsion per se offers the least satisfactory therapeutic results. In a later contribution we shall report on the relative frequency of each of these groups. Suffice it to mention here that most of the cases fall into the first group in which a marked rise of paralyzed hemidiaphragm occurs with replacement of the mediastinum to its original anatomic position, at least as can be judged from the roentgenograms.

## CONCLUSION

In a number of patients treated with a compressive type of pneumothorax for a long time, the lung remains shrunken and cicatrized and fails to reexpand at the end-stage of treatment, leaving an empty pleural cavity to be filled in by the retraction of the adjacent structures. A new train of symptoms often develops as a result of disturbance in the cardiovascular system caused by an extreme displacement and distortion of the mediastinal structures.

The mechanism of compensation for loss of lung volume at the termination of pneumothorax is discussed; the close interrelationship of all these factors of compensation and its bearing on the therapeutic methods of procedures are indicated.

Phrenic exeresis is the least disturbing operation and very effective in relieving symptoms caused by the marked mediastinal shifting. The clinical and anatomic changes following phrenic avulsion at the end-stage of pneumothorax may be divided into three groups:

(a) Cases in which a marked rise of the paralyzed hemidiaphragm into the chest occurs replacing the mediastinum to its former anatomic position with complete cessation of symptoms.

(b) Cases in which only partial mechanical readjustment of the mediastinum is noticed, but symptomatic relief invariably follows.

(c) Cases in which only a slight elevation of the diaphragm follows, and pneumothorax insufflations have to be continued in order to prevent mediastinal deflection, but the intervals between treatments are very much lengthened.

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# PHRENICOEXERESIS*

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IT IS safe to say of the various collapse procedures which have been used in the treatment of pulmonary tuberculosis, with the exception of pneumothorax, that thoracoplasty and avulsion of the phrenic nerve have withstood best the test of time and experience. While, however, thoracoplasty seems every day to find more favor among the surgeons and the indications for its use are being broadened, opinions about phrenicoexeresis are far from unanimous. In fact, some specialists would have this operation restricted to the localized basal lesions only, if not discarded altogether. They believe that its application, especially in cases with upper lobe lesions, is not only useless, but even dangerous, inasmuch as it delays a thoracoplasty, a delay which might prove fatal for the patient. The controversy regarding the advantages or disadvantages of each procedure seems to have overshadowed more important considerations, namely, their mechanics and the physiopathologic changes produced by them in the tuberculous lung. Being direct offsprings of pneumothorax, we take for granted that their action must be similar to that of their parent, forgetting that today our views regarding pneumothorax are somewhat different from those which inspired Forlanini to propose and practice it and which still prevailed when thoracoplasty and phrenicotomy were successively introduced as its substitutes. It is the purpose of this paper to point out that phrenicoexeresis may be effectively used in the treatment of apical tuberculosis and to analyze some of the more important principles involved.

We shall not make an exhaustive analysis of the hypotheses evolved in the past years to explain the beneficial clinical and anatomic results of pneumothorax. It is enough to say that a wider application of the method has induced us to substitute for the rigid concept of strict functional rest through compression of the whole lung, the more plausible one of rest through retraction, which avails itself largely of the greater tendency that the atelectatic and partly fibrotic tuberculous tissue has to recoil under pneumothorax, as compared to the expansile healthy lung. This is sufficient to minimize the respiratory trauma to which the diseased area, having lost its elasticity and being therefore unable to follow the movements of the chest wall, is unduly subjected. At the same time, understanding better the circulatory changes taking place in the lung as a result of its collapse, we also realize the important rôle

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Received for publication, Nov. 20, 1935.

they play in the healing of the lesion. The connective tissue proliferation is especially increased by the venous and lymphatic stasis with anoxemia which are always produced in some degree by pneumothorax, even in a lung moderately collapsed. In other words, pneumothorax acts simultaneously to check through rest the progress of the disease and to create the irrigatory conditions which stimulate and accelerate the reparative processes.

There is no doubt that the more the lung collapses or, to use a phrase which perhaps more accurately describes the process, the more the lung retracts, the greater will be the chances for complete rest and healing; but experience has taught us that we do not need to reach the extremes in order to obtain the desired result. Unless we take this point of view, we should be unable to explain the surprisingly good results of the bilateral and so-called selective or hypotensive pneumothorax, in which the retraction of the diseased area plays the major rôle, and the rest afforded to the lung as a whole is only relative.

In modifying our theory of complete functional rest of the organ, it also becomes necessary to reconsider our previous conceptions about the closure of cavities. We were taught that compression of the lung was the "conditio sine qua non" to obtain a successful closure of the cavities, and we were told of their walls being brought together and healing like an ordinary abscess, of the lung being squeezed like a sponge, and so on. Aside from the fact that in selective collapse no positive pressures are used, today we are being convinced that we cannot exert with a manometric weight of a few cubic centimeters of water any real compression upon the lung, and certainly not upon a cavity surrounded by a more or less rigid area of infiltrated inelastic tissue. Furthermore, even if we could exert pressure and overcome with the ordinary pneumothorax apparatus the resistance of the cavity, the pleural absorption of the air is so rapid as to make the compression only temporary. During a series of studies, which will be reported later, we have found repeatedly that pressures of plus 15 to plus 20 at the end of refills have returned neutral at the end of one hour. These observations were made on patients who had received pneumothorax treatment for more than two years, some of whom had had pleural effusions with thickened pleura which is supposed to retard the absorption of air. The only operation by which real compression is exerted directly upon the cavity is apicolysis with plombage.

How then do cavities close? Coryllos[1] two years ago expressed the opinion that the disappearance of cavities during collapse therapy could be due to atelectasis resulting from a bronchial obstruction, and recently his theory has been experimentally confirmed by W. E. Adams and J. J. Singer[2] who, having obtained cavities in dogs, produced a bronchial stenosis with consequent atelectasis of the excavated lobe by introducing a silver nitrate solution in the bronchus. They found that as a result of the atelectasis, the cavities had become completely obliterated and were

replaced by scar tissue. Leaving open the question as to whether the bronchial stenosis is due to a kinking or to a plugging of the bronchus, as Coryllos seems to believe, or simply to a constriction of the fibrotic tissue around the bronchus,[3] this explanation of the disappearance of the cavities seems rational enough.

From the foregoing we can say that the mechanism of collapse therapy proceeds by stages which might be summarized in the following sequence: (1) Retraction: the lung, which even during full expiration is under permanent tension, is allowed to retract by reducing the negative pleural pressure. This retraction, for obvious reasons, is more marked in the diseased parts. (2) Resultant relative functional rest with venous and lymphatic stasis and anoxemia. (3) Scar tissue formation. (4) Eventual collapse and disappearance of the cavity as a result of bronchial stenosis. (5) Further retraction, made necessary by the gradual increase of fibrosis and the collapse of the cavity. It is evident that only a pneumothorax with a free pleural space can meet all these requirements.

Let us now consider the avulsion of the phrenic. We can a priori exclude in its mechanism any idea of compression, although, when this operation was introduced, that factor was still considered one of the mainstays of collapse therapy, and although there are still some phthisiotherapists who claim that the best results obtained with it are due to compression. Aside from the fact that in the best of circumstances the rise of the diaphragm is in many cases limited, if we consider for one moment only that in lesions of the upper lobe the diaphragm, in order to exert compression, must do so through a certain amount of healthy, normal lung tissue interposed between itself and the lesion, the obvious fallacy of this assumption is apparent. The same is true for the lesions of the bases, with the difference that the normal lung tissue is above the lesion. We cannot compress a hard, fairly resistant substance (tuberculous lesion) if behind it or between it and the compressing agent (elevated diaphragm) we place a material softer than both (normal lung).

At first glance we must admit that the apparent immediate results of the phrenic avulsion seem to fulfill only partly the requirements of a successful collapse therapy. The reduction of volume following the rise of the diaphragm has been calculated at from one-sixth to one-third of the lung volume. The resultant relaxation, although utilized to the utmost by the diseased area, is relatively limited and cannot be compared to that afforded by a selective pneumothorax. On the other hand, the actual rest obtained by the lesion after the rise of the diaphragm, deserves some consideration. The traumas to which a tuberculous lung is subjected arise from three different sources: (a) the expansion of the chest wall, (b) the pistonlike tug of the diaphragm, (c) and the cough. If it is true that with a paralyzed diaphragm there is a vicarious hyper-

activity of the intercostal muscles, it is also true that this will have slight effect on the upper portion of the lung, especially in individuals who have an abdominal type of respiration. The pulling of the diaphragm instead and, vice versa, its abolition are felt in the same degree at the apex as at the base, except in those cases in which thick fibrotic bands form a solid partition in the middle of the lung and through the pleura anchor the organ to the chest wall. As for the cough, which in many cases is the worst of all traumas, many of us have observed how this distressing symptom may be greatly relieved and may sometimes disappear after a phrenicoexeresis. Therefore, if not complete functional rest, we obtain at least rest from trauma.

But is that enough to produce the circulatory and other changes on which we also depend for the fibrotic transformation of the lesion and the disappearance of the cavities, especially in those cases in which no marked rise of the diaphragm follows the operation? Any one familiar with the operation (and many writers have emphasized the fact) knows that the improvements do not always correlate with the number of centimeters of elevation of the diaphragm, and that such improvements might occur even when the diaphragm appeared fixed and partly elevated before the operation.

This evident disproportion between cause and effect, while furnishing opponents of the operation with the strongest argument against it, has prompted numerous investigators to seek other possible explanations of the results. The conclusions arrived at by them are plausible enough to warrant a more careful analysis of the different effects of phrenic avulsion upon the lung, including of course the diaphragmatic paralysis. These hypotheses originate from the observations principally of Felix who found that the phrenic nerve receives numerous sympathetic fibers from several ganglia. These fibers are, according to some authors, so numerous as to form one-third of the nerve's bulk. However, although we are sure of the presence of these fibers and of some of their sources, we are less sure, for lack of histologic evidence, of their ultimate course and of the functions to which they are delegated. According to some they spread upon the serous membranes of the thoracic cavity; according to Felix they have a reflex vasomotor control upon the lung; and according to others they enter the lung directly and share in its innervation.

Margaria[4] reports the interesting results of a series of experiments upon dogs. With a thermoelectric cell introduced through a catheter in a bronchus and connected with a galvanometer, he registered the changes of temperature of the bronchial air during the stimulation of the exposed phrenic nerve, after its section and during the stimulation of its peripheral stump. He was led to this particular experiment by the surmise that the vasoconstrictor fibers present in the sympathetic trunks would, if stimulated or cut, determine changes of temperature in the

organ they innervate, and therefore some thermic changes would be found to occur in the bronchial air if the lung were to receive any part of the sympathetic fibers contained in the phrenic. He noted:

(1) "The stimulation either of the phrenic or of its peripheral stump determines a sure and constant lowering of the temperature of the bronchial air."

(2) "The cutting of the phrenic determines a sure and constant increase in the temperature of the bronchial air." These changes of temperature he attributes to "the changes in the irrigatory condition of the lung, and their occurrence following the stimulation or section of the phrenic nerve is explained by the existence in the trunk of the phrenic of vasoconstrictor sympathetic fibers which preside over the innervation of the pulmonary or bronchial vessels."

Belli[5] is of the opinion that the blood stasis due to sympathetic vasoparalysis should also be considered in the results of phrenicotomy. He used the oncographic method of studying the changes in the lung volume during the stimulation of the phrenic in animals kept alive with artificial respiration. He exposed and resected the nerve both at the neck and just above the diaphragm, delivering at the same time the lung from the chest cavity. He writes: "The graphs obtained . . . permit me to state that the faradic stimulation of the phrenic nerve at the neck . . . determines, after a period of latency varying from five to seven seconds, a diminution in the volume of the lung which is prolonged for a fraction of time after the stimulation has been discontinued and then gives place to a slow and gradual return to the normal volume. Such diminution of the pulmonary volume must be put in relation to a vasoconstriction occurring as a result of the faradic stimulation of the distal stump of the phrenic, because I had, previous to the experiment, ligated the homologous bronchus." He adds that the intensity of the vasoparalysis varies whether the phrenic is simply cut at the neck, or is partly or completely avulsed because the number of its sympathetic fibers increases during its course in the thoracic cavity.

Many others have studied the conditions of the lung after variable periods following a phrenic operation. The majority of them, although disagreeing on other facts, seem to agree at least upon one constant finding: the presence of a more or less marked degree of congestion, especially of the veins and of the capillaries. Bettini and Celotti,[6] working on animals, made a comparative study of the histology of the lung after pneumothorax, phrenicotomy, and thoracoplasty. One of the two (B.) had already studied the modifications of the tuberculous lung in man after a phrenic operation, and reported to have found congestion and marked desquamation of the alveolar epithelium, which in some places filled the alveoli with desquamated cells. This confirmed the findings of others and especially of Donati,[7] who also had noted marked hyperemia and alveolar desquamation, which he attributed to disturb-

ances of sympathetic origin more than to the collapse produced by the rise of the diaphragm. Bettini and Celotti write: "Also in phrenicotomy, as in pneumothorax, an activity of the mesenchymal elements can be observed in the treated lung. . . . In the animals sacrificed two months or more after the phrenicotomy, the alterations regarding the alveoli are more or less the same, while in some areas could be noted a noticeable proliferation of the peribronchial and perivascular elements and of the subpleural connective tissue so that in some of these areas was reproduced the picture of an initial fibrosis." They also found a great similarity in the circulatory modifications occurring in the lung treated with pneumothorax and those treated with phrenicotomy or thoracoplasty. In all cases there was evident a marked congestion especially of the veins and of the capillaries.

These observations, and others with similar conclusions, are significant. They would seem to indicate that, even though the histologic evidence is lacking, the phrenic nerve, somehow, takes an active and direct part in the innervation of the lung and that if this participation is interrupted by the section of the nerve, the lung undergoes certain definite circulatory changes which are similar to those produced by pneumothorax or thoracoplasty. If to these changes we add the rest and retraction afforded by the paralysis and elevation of the diaphragm, we can more easily understand how the combination of these factors might stimulate, after a short period, the reparative process around the lesion.

Furthermore, leaving aside the question as to the true function of the alveolar epithelium in the exchanges between air and blood, could not its active and abundant desquamation, found to be so pronounced after a phrenic operation, impair the permeability of the alveoli and so produce a greater degree of anoxemia, which not only is important in the formation of fibrosis, but also because it seems to check the growth and vitality of the tubercle bacillus?

That the results of phrenicoexeresis upon the tuberculous lung must be due to some other factor than a simple paralysis of the diaphragm becomes more evident when we consider this operation in combination with some types of pneumothorax. This procedure has been advocated by many as a very efficient means of turning an unsatisfactory collapse into a successful one, the explanation being that both a better compression and a better rest of the lung are obtained. Even if this might appear true in cases in which the base is adherent to the diaphragm so that the activity of this muscle interferes with a complete rest of the lung, this explanation alone is no longer sufficient for those successful cases reported, in which the base was free, the lower lobe collapsed and the cavity in the adherent upper lobe, or the whole lung was free and the cavity central or hilar.[8] In such conditions the rest of the lung was not interfered with by the diaphragm, and more compression could have been obtained, if possible, simply by giving more air at higher pressures.

Several authors, among them Tice and Hruby,[9] are of the opinion that phrenicectomy, combined with pneumothorax, will enable us to lengthen the intervals between refills. Is this result due only to the fact that the paralyzed diaphragm slows down the pleural absorption of the air and therefore prevents the lung from reexpanding? We have already said that positive pressures in the pleural cavity can be maintained only for a short time. Could there not be some other cause directly inherent in the lung? It has been suggested that the phrenic nerve, through its sympathetic fibers, might have some control upon the smooth muscles of

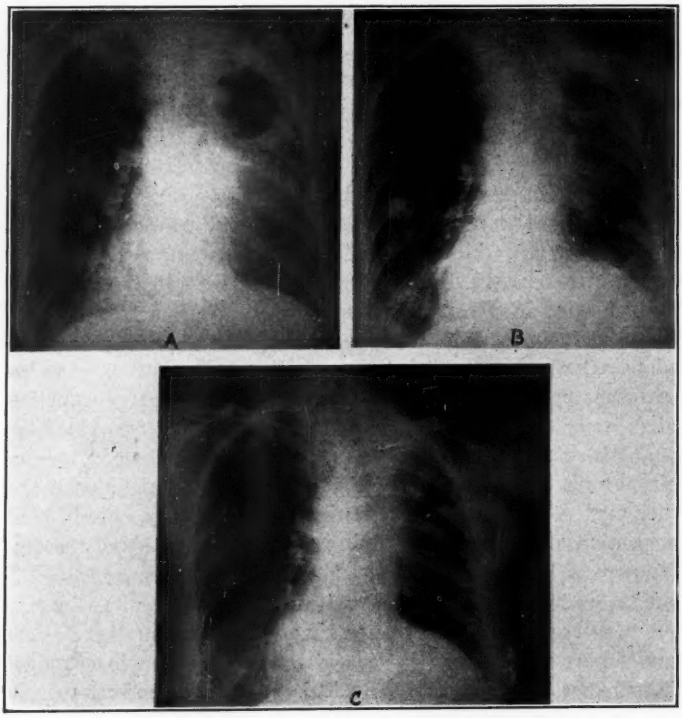


Fig. 1.—Female, aged fifty years. In hospital since December, 1932.
*A*, Film taken October, 1934. Phrenic avulsion performed December, 1934.
*B*, Film taken March, 1935. The cavity is still present but is considerably reduced in size.
*C*, Film taken May, 1935. The cavity has become atelectatic.

the bronchi so that its section would enhance pulmonary rest.[10] This is not idle speculation. After the recent studies of Luisada[11] revealing the rôle played by these muscles in the physiomechanics of respiration, the importance of this factor in collapse therapy must be admitted. Therefore, the delayed reexpansion of the lung, which would permit longer intervals in the refills, might be due not only to a paralyzed diaphragm,

but also to the inability of the lung per se to reexpand. *Such a possibility would also lead to the hypothesis that an impairment of the tone of the smooth muscular system would render the already damaged bronchial walls more collapsible, and therefore an atelectasis more likely to occur.* This possibility is, in our opinion, worthy of consideration, especially when we are confronted with the remarkable changes occurring in some lungs shortly after a phrenicoexeresis as evidenced by the roentgen films shown in this paper. They were selected as being the

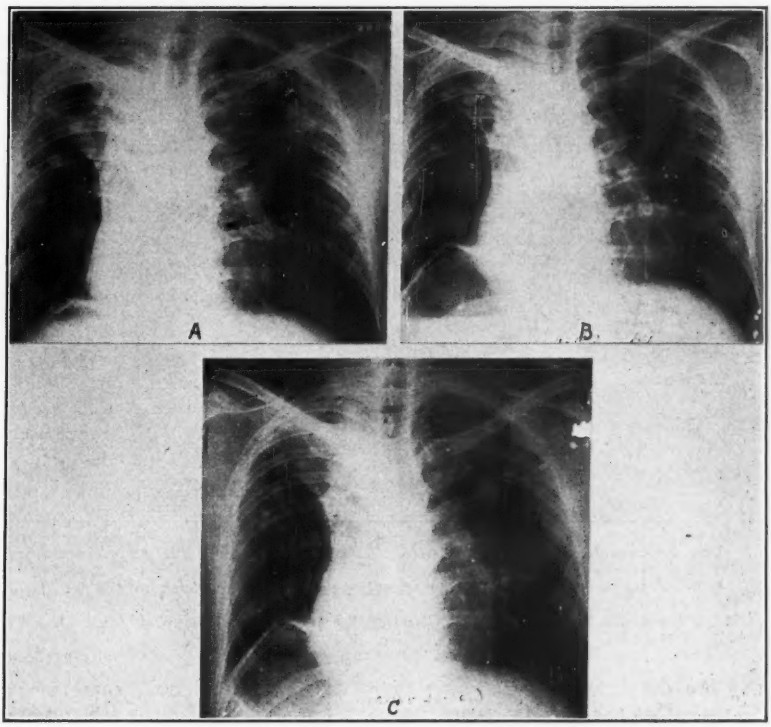


Fig. 2.—Male, aged twenty-seven years. In hospital since May, 1934.

*A*, Film taken February, 1935. Large cavity in the left infraclavicular region. Phrenic avulsion performed June, 1935.

*B*, Film taken August, 1935. Noticeable decrease in the size of the cavity.

*C*, Film taken October, 1935. The cavity has become atelectatic. Observe that in both cases (No. 1 and No. 2) the rise of the diaphragm has been comparatively small.

most interesting of a small series of 40 operations performed by one of us (J.) in our hospital. The lesions were all far advanced in extent and in type; the patients had been in sanatoriums for periods varying from months to several years, and repeated attempts to establish pneumothorax had been unsuccessful. To all appearances a phrenic avulsion

would have been only a waste of time and a thoracoplasty should have been considered without delay. Nevertheless, the large cavities have become atelectatic, the sputum is bacilli free, and in every respect the cases can be considered at least quiescent. Whether the bronchial stenosis which produced the atelectasis of the cavities is due to a constriction or to a kinking we cannot know. What we know is that it occurred after the avulsion of the phrenic nerve. Are we sure that in these same patients the same results could have been obtained with a thoracoplasty?

There are many reports on the subject of phrenic avulsion which afford statistics with varying percentages of successes. We can neither discard them with the simple statements that the patients who did well would probably have done equally well without the operation, nor can we explain them if we persist in the mistake of identifying collapse therapy with compression of the lung. As we have said before, paralysis

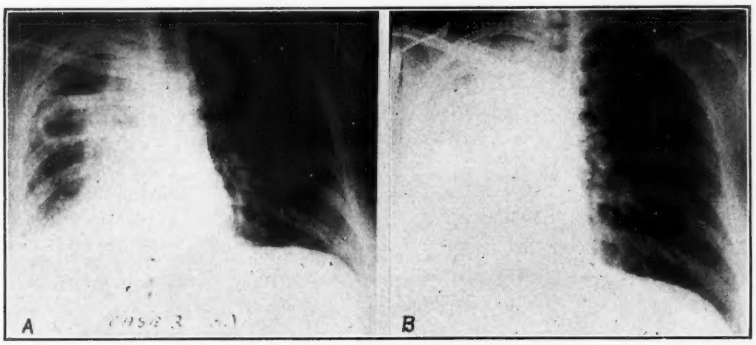


Fig. 3.—Female, aged thirty years. Tuberculosis of several years' duration. Phrenic avulsion November, 1923.

*A*, Film taken one day after the operation; two large cavities in the left lung with fluid levels.

*B*, Film taken May, 1935. Atelectasis of the left lung. The upper cavity is still visible, but probably is shut off because the sputum is negative.

of the diaphragm cannot, any more than pneumothorax, compress a tuberculous lesion of the lung. Nor can rest alone, if considered strictly as a mechanical factor, be responsible.

The opponents of phrenic avulsion have two main objections to it. The first is that while we wait for its results, the lesions may spread and make a thoracoplasty later impossible or at least a greater risk with less chance of success. We cannot agree with that. It all depends on which cases we consider good risks for thoracoplasty. If we want to hold down its mortality rate, and expect a high percentage of cures, we will select cases of long standing, with well-circumscribed, nonprogressing lesions. These cases very seldom spread or have hemorrhages, and, if kept at rest, will be as good operative risks six months later as they were earlier.

The second objection is that the paralysis of the diaphragm, previous to thoracoplasty, might enhance postoperative spread, mainly because it impairs the mechanism of cough. We know from experience that one of the first observations of a patient after a phrenic avulsion refers to the ease with which he is able to raise sputum, even though the cough has decreased considerably. Moreover, those who raise this objection forget that we give patients so many opiates immediately after thoracoplasty that, paralysis or no paralysis of the diaphragm, the cough reflex is so greatly impaired as to make a spread possible anyway.

Incidentally, it is worth while at this point to ask oneself whether the better results lately reported with thoracoplasty could not be due in part to the fact that this operation is now more often either preceded or followed by a phrenic avulsion. This deduction seems plausible if we consider that while the technic of paravertebral thoracoplasty has not been radically improved in these last few years, the standard for the selection of the cases has been lowered, because we now operate on patients who would have been considered poor risks a few years ago.

The above considerations are not an attempt to prove the superiority of phrenic avulsion over pneumothorax or thoracoplasty. Pneumothorax is still, by far, the procedure of choice whenever and wherever possible. We must consider the other two operations merely as its substitutes, which, like most substitutes, have their disadvantages and do not measure up to the original. The success of their application depends too much on elusive combinations of different elements over which we have no control. The type, the size, and the site of the lesion, the defensive powers of the individual, the ability of the lung to contract, the integrity and resistance of the bronchial walls, and so many other factors which vary from patient to patient, make it impossible for us to foresee what will be the result of a given operation. Furthermore, thoracoplasty, which represents the patient's last appeal, is still being followed by serious complications and a fairly high mortality, while phrenicoexeresis presents few dangers or complications and can easily be performed even in small hospitals lacking facilities for a major operation. All in all, we feel that the latter proves to be very satisfactory in a good number of cases. This number may vary, but statistics should not influence our judgment. Even a low percentage of cures should be enough to oblige us to give it a fair trial when pneumothorax has failed and before deciding upon a thoracoplasty.

## CONCLUSIONS

1. Collapse therapy is based primarily on retraction and not on compression of the lung.

2. Cavities may disappear as a result of atelectasis.

3. It is possible that the phrenic nerve exerts through its sympathetic fibers a direct control upon the pulmonary innervation.

4. Therefore, it is also possible that the discontinuance of this control produces in the lung such trophic and other changes as to enhance the development of fibrosis and probably of atelectasis.

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# ACUTE DILATATION OF THE STOMACH FOLLOWING LEFT-SIDED PHRENIC PARALYSIS AND THORACOPLASTY*

## Two Fatal Cases and Two Cured by Continuous Gastric Suction

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THE occurrence of gastrointestinal symptoms following left-sided phrenic paralysis is not uncommon and has been reported by a number of authors. Stanbury reported two fatal cases of acute dilatation of the stomach following phrenic paralysis. These were the only two fatal cases Alexander could find in the literature. Francis Trudeau noted a number of cases in which gastric disturbances followed left-sided phrenicectomy. While he found that these disturbances might last for a week or even several months, he states that they always clear up eventually. Ballon, Wilson, Singer, and Graham have found cases of eventration of the diaphragm in which a permanently large stomach bubble under the highly arched diaphragm reached to the level of the third intercostal space. They found that when left-sided phrenicectomy was followed by a marked rise of the left side of the diaphragm, there was an increased angulation of the abdominal portion of the esophagus. They could find no experimental evidence, however, to indicate that phrenicectomy results in obstruction of the lower part of the esophagus, or proof that phrenicectomy may produce cardiospasm.

In the four cases which we are reporting the patients had acute dilatation of the stomach following a left-sided thoracoplasty which was done after phrenic paralysis on the same side. In two of the cases the condition was recognized at necropsy. In the other two cases continuous drainage of the stomach according to Wangensteen's method was instituted as soon as the symptoms appeared. Both of these patients obtained immediate relief from their symptoms and completely recovered.

Case 1.—L. T., male, aged forty-one years, had a history of advanced pulmonary tuberculosis of seven years' duration, with bilateral cavitation. The patient had had a left-sided phrenic exeresis elsewhere several years before thoracoplasty. Examination just before the latter operation showed the lesions in the right lung to be almost completely healed, but in the left lung there was a large apical cavity. The blood pressure was 120 systolic and 80 diastolic; the pulse rate was 80. Roentgenograms showed a 9.5 cm. rise of the left hemidiaphragm. The electrocardiogram showed slight myocardial damage with no other change. Following a first-stage thoracoplasty in which the upper three ribs were removed, the patient's

*From The Thomas-Davis Clinic.
Received for publication, March 28, 1936.

convalescence was satisfactory until the fourth day. The patient had mentioned at the time his history was taken that he was sensitive to milk. On the afternoon of the fourth postoperative day the attending nurse insisted that he drink an egg-nog. Within thirty minutes the patient started to vomit and became dyspneic and cyanotic. On examination his pulse was rapid and thready; the point of maximum intensity of the heartbeat was at the third intercostal space inside the midclavicular line. He was tympanitic from the fourth intercostal space to the base, and no breath sounds were heard on the left side. Roentgenograms showed an enormous dilatation of the stomach extending to the third intercostal space. The patient died within a few hours.

At necropsy the stomach was found to be tremendously dilatated, extending as high as the third rib at the anterior axillary line. The diaphragm was atrophic but not ruptured. The mediastinum was markedly displaced to the right. The left lung was well collapsed by the thoracoplasty and the elevated diaphragm, forming a small pyramidal mass which filled the space above the dome of the diaphragm. There was a compensatory emphysema of the right lung.

CASE 2.—L. H., male, aged twenty-six years, gave a history of advanced pulmonary tuberculosis of two years' duration. He had had a temporary phrenic interruption on the left side six months previously. No abdominal distress had been noted following the phrenic interruption. Systolic blood pressure was 130 and diastolic 110; the pulse was 76. Roentgenograms showed a 4.5 cm. rise of the left hemidiaphragm. The second day following an upper stage thoracoplasty in which three ribs were removed, the patient became greatly distended and complained of abdominal pain. He was dyspneic and cyanotic. His pulse was thready and the rate rose to 150 per minute. He was placed in an oxygen tent which made him more comfortable, but the distention, dyspnea, and cyanosis continued until the time of his death on the fourth postoperative day.

Postmortem examination showed a dilatation of the stomach which reached the third intercostal space. The intestines were very much dilated, and the mediastinum was pushed to the right. The left lung was completely collapsed. There were no other significant findings.

CASE 3.—G. G., male, aged forty-two years, gave a history of pulmonary tuberculosis of eight years' duration. Left phrenic exeresis had been done elsewhere four years previously. Examination showed a huge cavity at the left apex. Systolic blood pressure was 108, diastolic 82. The pulse rate was 84 per minute. Roentgenograms showed a 5 cm. rise of the left side of the diaphragm. Following the upper stage thoracoplasty, which included the first three ribs, the patient complained of abdominal distress and pain on the left side but made an uneventful recovery. The second stage consisted of removal of the fourth and fifth ribs. There was pain in the lower part of the chest following this operation, but the patient made a satisfactory recovery. The third operative stage was an anterolateral thoracoplasty and was not accompanied by distressing symptoms. An hour after the fourth stage, which consisted in removal of the sixth and seventh ribs, the patient became dyspneic. He also complained of pain along the left costal margin. Fluoroscopic examination showed the diaphragm to be elevated to the second intercostal space. It was recognized that the stomach was acutely dilated and was elevating the diaphragm. A tube was passed through the nose into the stomach which was continuously drained according to Wangensteen's method. About 2,000 c.c. of gas was withdrawn within a few minutes. Immediate relief from pain and dyspnea followed. The tube was removed on the third day. The patient again became dyspneic and complained of rhythmic pains in the left upper quadrant of the abdomen. Reinsertion of the tube again brought about relief. Two days later the tube was again removed but

the symptoms returned. He was again relieved when the tube was reinserted. During the rest of the patient's convalescence, the temperature and pulse were normal. While it was not necessary to leave the tube in place continuously after the seventh day, it was reinserted three different times for short intervals when there was a recurrence of the pain in the left upper quadrant of the abdomen. The patient has since made a very satisfactory recovery.

CASE 4.—W. R. M., female, aged forty years. The patient gave a history of pulmonary tuberculosis of fourteen years' duration. Examination revealed a large cavity in the left apex. The systolic blood pressure was 110 and diastolic 80; pulse was 96 per minute. The patient received pneumothorax for nine months, but this was abandoned just before starting the thoracoplasty. Phrenic nerve interruption was added to the pneumothorax three months after the latter was instituted. The diaphragm did not rise following the phrenic paralysis in the presence of the pneumothorax. There was no abdominal distress after the phrenic interruption. At the first stage of the thoracoplasty the first, second, and part of the third ribs were removed. Convalescence after this operation was uneventful. The second posterior stage included removal of part of the third, and the fourth and fifth ribs. The postoperative course was normal. An anterolateral stage was later performed with no untoward effect. The third posterior stage consisted in removal of the sixth, seventh and eighth ribs. Within an hour after the completion of this last stage of the operation the patient became dyspneic and cyanotic, and her pulse rose to 140 and was thready. The condition was recognized as acute gastric distention, and continuous suction was started. Almost immediate improvement resulted. Continuous suction was maintained for forty-eight hours. She had no further trouble and the rest of the convalescence was uneventful.

## CONCLUSIONS

In the four cases reported, acute dilatation of the stomach followed left-sided thoracoplasty operations in which the left hemidiaphragm had been previously paralyzed. In one of these cases there was a marked rise of the diaphragm before the thoracoplasty was begun. In the other three cases the rise of the diaphragm was not marked. All the patients showed marked dyspnea, cyanosis, and tachycardia with accompanying abdominal distention. Two of the patients died, the condition being recognized at autopsy. In the other two patients, rapid relief and recovery resulted from the use of continuous suction through a nasal catheter as employed by Wangensteen in the treatment of intestinal obstruction.

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# ANESTHESIA IN THORACIC SURGERY*

## With Special Reference to Cyclopropane

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UNUSUAL problems are presented to the anesthetist who safely carries a patient with a disabling pulmonary lesion through a major thoracic operation. He must produce anesthesia and at the same time provide an adequate supply of oxygen. He must keep the tracheobronchial tree aspirated and control the intrapulmonic pressure. Closed inhalation anesthesia has done much toward the solution of many of the problems peculiar to the thoracic case. The maintenance of an adequate anesthesia with simultaneous administration of sufficient amounts of oxygen to meet requirements has been one of the real problems in thoracic work. The more reduced the absorbing surface in the lung, the more difficult it is to provide sufficient oxygen. The weaker and the more anemic the patient, the less tolerant he is of anoxemia. It is our aim in this discussion to point out, first, some of the handicaps present in anesthetizing this class of patients, second, to outline what might be considered an ideal anesthesia, and third, to consider cyclopropane as the anesthetic agent which more closely approximates the ideal than any other.

### DIFFICULTIES PECULIAR TO THORACIC CASES

Patients requiring thoracoplasty for tuberculosis, thoracotomy for lung abscess, or pneumonectomy for malignancy are all poor risks from the anesthetic standpoint. A general statement of this kind can be made for several reasons.

1. In the first place, such patients are usually in a poor physical state. They have been victims, in many instances, of a protracted illness and have spent long periods of time in bed. Secondary anemia and nutritional disturbances are frequent accompaniments. Often there has been absorption of septic material over a considerable period of time. Such patients withstand surgical trauma and loss of blood poorly. *It is well known that they also show a marked intolerance for slight degrees of anoxemia.* This group, therefore, react adversely to any anesthetic mixture requiring such high concentrations of the anesthetic agent itself that the oxygen supply must necessarily be greatly reduced.

*From the Departments of Anesthesia and Thoracic Surgery, The Lahey Clinic.
Received for publication August 20, 1935.

2. By virtue of the fact that the pathologic process itself is situated within the organ of respiration, the anesthetist's problems are obviously rendered more complicated.

(a) The absorptive surface of the lung is reduced. This is true both for the absorption of the anesthetic agent as well as for the oxygen.

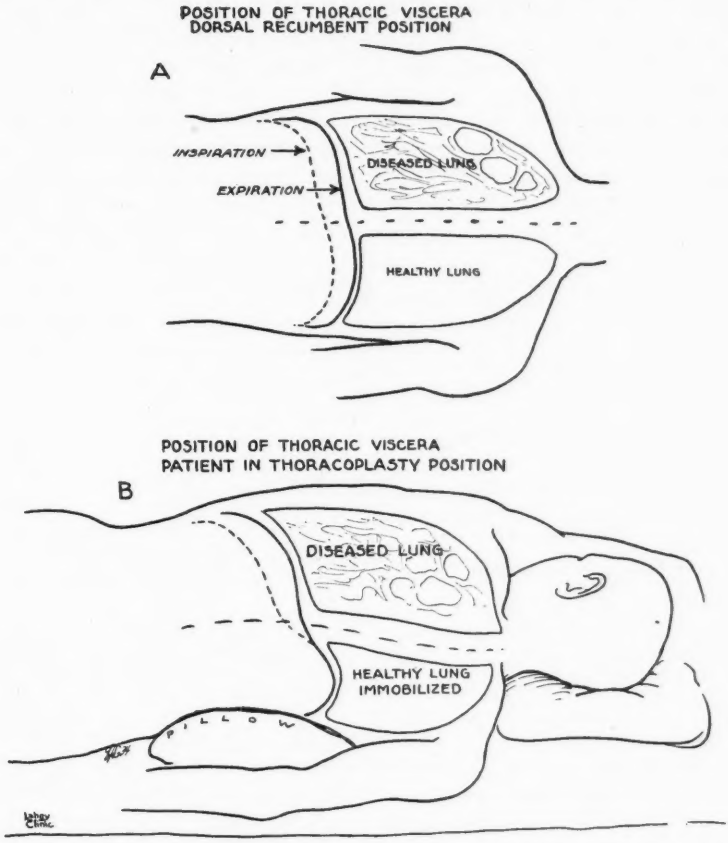


Fig. 1.—*A*, Diagram illustrating the relative position of the thoracic viscera and the range of excursion of the diaphragm when the patient is in the dorsal recumbent position.

*B*, Diagram illustrating the position of the thoracic viscera when patient is placed in a position suitable for thoracoplasty. The better lung is in the dependent position. The excursions of the thoracic cage are impaired. The dependent diaphragm, likewise, is restricted in its motion. The total volume of the better lung and the vital capacity of patients in this position are reduced.

(b) Abnormal amounts of mucus and pathologic secretions in the tracheobronchial tree must be contended with.

(c) There is a marked tendency to cough. This overactive reflex action may interfere with a quiet, smooth induction.

(d) The position of the patient on the operating table which permits of an operative procedure on the pathologic side interferes in two respects with the work of the anesthetist. In the first place, the chance for a spill over of secretions into the good lung is increased. Second, the functioning good lung occupies a dependent position. The weight of the body limits rib movements. Diaphragmatic action is reduced by the weight of the viscera against the dependent diaphragm. Adams and Pillsbury[1] have called attention to the high and fixed position of the diaphragm on the dependent side in the lateral, horizontal position. In order to verify these findings, we studied by x-ray and fluoroscopically a normal subject in the dorsal recumbent and in the lateral horizontal positions. In Fig. 1 is reproduced a tracing from roentgenograms made in these two positions. Note that when the patient is in the thoracoplasty position, the area of the better lung is very definitely decreased. The diaphragmatic excursions are also limited on that side. In Fig. 2 is

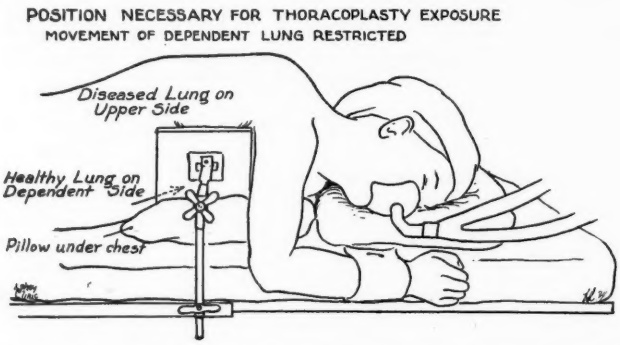
POSITION NECESSARY FOR THORACOPLASTY EXPOSURE
MOVEMENT OF DEPENDENT LUNG RESTRICTED
Diseased Lung on Upper Side
Healthy Lung on Dependent Side
Pillow under chest

Fig. 2.—Diagram illustrating the effect of the position of the patient on the movements of the thoracic cage. The lateral position, the chest support, and a pillow beneath the chest all contribute to reduce the excursions of the dependent thoracic cage. Therefore when a patient with a lung volume reduced by disease is placed in such a position, high concentrations of oxygen are essential.

shown a drawing of a patient in position for an operation on the posterolateral aspect of the right chest. Note that the pillow beneath the chest and the anterior chest support provide an excellent exposure of the thoracic cage, but the movements of the dependent lung are thereby restricted. The already limited lung volume is still further reduced by the position of the patient on the table.

3. The third factor peculiar to anesthesia for thoracic cases is that of the open pneumothorax, should an intrapleural procedure be undertaken. Considerable embarrassment to respiration and to the circulatory system may be a consequence of an opening of the pleural cavity unless precautions are taken. Situations causing the most concern arise when the visceral pleura is free, the mediastinum mobile, and when the pleural opening is relatively small so that more air enters the pleural cavity than leaves with each respiratory cycle. The use of the closed in-

halation type of anesthesia with ability thus to control intrapulmonic pressure, the preliminary production of a pneumothorax in free pleura cases, and the administration of high concentrations of oxygen during the period of time that the chest is open all tend to lessen the danger of open thoracotomy. In fact, today with the aid of proper anesthesia, exploratory thoracotomy can be carried out with as great safety from the respiratory standpoint as exploratory laparotomy.

4. The fourth point of difference in the management of anesthesia in thoracic cases has to do with the few hours in the immediate postoperative period. In many cases, especially in lung abscess and tuberculous subjects, the diseased lung is not actually removed at the time of the operation so that internal drainage of these areas aided by the cough reflex must not be interfered with. Furthermore, the respiratory ability of the patient is handicapped by the thoracic wound as well as by the pathologic lung. Any degree of anoxemia throughout this period should be prevented. The character and dosage of the preoperative medication as well as the anesthetic agent itself must be so selected that their influence on respiration and the cough reflex will not be extended into this early postoperative period.

## THE IDEAL ANESTHESIA FOR THORACIC OPERATIONS

From the standpoint, therefore, of the type of patient, the conditions of the respiratory organ, and the restrictions placed upon its functioning capacity, the problem of the administration of an anesthetic for thoracic work is quite unlike that presented in general surgery. With these facts in mind we might consider what should be the ideal anesthesia for thoracic surgical procedures.

1. The anesthetic agent should be free of any deleterious effect on the patient, either immediate or remote, due either to toxicity of the agent itself or from respiratory depression or from the fact that it is such a weak anesthetic that it must be given in concentrations sufficiently high to necessitate a state of partial anoxemia.

2. The gas mixture should be nonirritating to the respiratory passages.

3. The anesthesia should be rapid of induction and pleasant for the patient to take. The induction should be without an excitement stage, devoid of struggling, and without an initiation of coughing spells.

4. The anesthesia should give respiratory movements that are quiet during the operative procedure, yet of sufficient magnitude to afford adequate filling of the alveoli. No undue mechanical strain should be placed upon the abnormal lung. Uneven, jerky, violent, or wide excursions of the chest may spread an acute inflammatory process or tear a fibrotic lung.

5. The anesthesia should at all times be under the direct control of the anesthetist so that he may at will either decrease or increase its depth.

6. The action of the anesthetic should cease when its administration is discontinued so that there is a rapid return of consciousness and of the cough reflex.

7. Intrapulmonic pressure should at all times be under control of the anesthetist.

8. Adequate facilities for the aspiration of material from the respiratory passages should at all times be available.

9. The anesthetic mixture should, if possible, be free from an explosive hazard.

### AVAILABLE ANESTHETIC AGENTS

Practically all the available anesthetic agents have been used in this field of surgery. We have, therefore, a choice of using a general anesthesia or a regional anesthesia, the latter including local infiltration, intercostal nerve block, and spinal anesthesia.

Local or regional anesthesia, practically every one agrees, is satisfactory and is the anesthesia of choice for minor procedures such as drainage of empyema, thoracotomy for lung abscess, for open or closed pneumonolysis, and for extrapleural pneumonolysis (plombage). Subarachnoid block or spinal anesthesia has been used by some for major thoracic operations. We fear its depressing effect on serious risk patients and therefore do not use it for any type of thoracic operation.

### AVERTIN

To produce general anesthesia without inhalation methods, tribromethanol, commercially known as avertin, is undoubtedly the most common drug used. The ease of induction for the patient, the freedom from postoperative nausea, and the quiet breathing on the operating table all are factors which have contributed to its popularity. We have used it only as a basal anesthesia, supplemented by gas. Even by this method, in our experience, it is unsatisfactory for the majority of thoracic operations. There is frequently a marked lowering of blood pressure. A definite depression of respiration and of the cough reflex follows its administration, and this effect extends for several hours into the early postoperative period. In our experience in thoracic work over half of the patients showed a variable degree of cyanosis postoperatively. We found it frequently necessary to put such patients in an oxygen tent for a period of twenty-four to seventy-two hours following operation in order to relieve anoxemia and insure a safe convalescence.

From the standpoint of comparison, it would be well briefly to consider some of the various inhalation anesthetic agents which are available.

### NITROUS OXIDE

Nitrous oxide is perhaps the most widely used of all inhalation anesthetic agents in thoracic surgery. It has also been responsible, in our hands, for many of the difficulties in carrying thoracic patients through

their operation safely. Struggling on the table, deep, forceful respirations, then cyanosis, and a rising pulse were commonplace occurrences. Nitrous oxide has the distinct disadvantage of requiring very high concentrations of the gas, usually 90 per cent or more, to maintain anesthesia. This concentration does not afford sufficient oxygen, 10 per cent or less, for the average patient who starts out with the handicap of an impaired absorptive surface. Miller[2] and others report, however, that the oxygen percentage can be increased if this anesthesia is given under an increased pressure equivalent to approximately 4.5 inches of water. We have had no experience with this method of administration. It would seem that all the commendable features of nitrous oxide, namely, a nonexplosive, nonirritating, and controllable gas, are completely overshadowed by its great failing, the inability to administer with it sufficient amounts of oxygen.

### ETHYLENE

Ethylene has some advantage over nitrous oxide from the standpoint of oxygen content of the gas mixture. The concentrations of ethylene (80 to 85 per cent) permit an oxygen percentage of 15 to 20 per cent. This margin, however, is still too narrow to insure at all times adequate oxygenation in the crippled pulmonary patient. Ethylene has the disadvantage of being explosive in lower concentrations. This danger, we feel, is practically negligible if proper precautions against ignition are taken. Furthermore, the mixtures usually employed in anesthesia are outside the explosive range.

### ETHER

Ether administered by either the open or the closed method will produce anesthesia with an adequate oxygen supply for most patients. It is frequently used to supplement nitrous oxide or ethylene, and so employed has found its widest application in this field. The obvious objection to ether in pulmonary cases is its irritation of the mucous membranes and its effect on bronchial secretion. That quiescent tuberculous lesions may be activated by its use has been the contention of many.

### ACETYLENE

Acetylene has been used considerably in Europe, particularly in Germany, and has had limited application in this country. We have had no personal experience with its use. It is an effective anesthetic with higher concentrations of oxygen than any of the above mentioned drugs. It requires a more cumbersome apparatus for its administration than other gases, and it has the added disadvantage of being more highly explosive.

### CYCLOPROPANE

We come now to the anesthetic agent which we feel at the present time to be the most satisfactory for thoracic operations when a general anes-

thetic is required. During the past two and one-half years, we have used this type of general anesthesia in thoracic work to the practical exclusion of all others.

Cyclopropane or trimethylene is a comparatively new anesthetic agent. It was first used on animals in 1928 by Lucas and Henderson.[3] The first report of its clinical use was that of Waters and his associates.[4, 5] It is

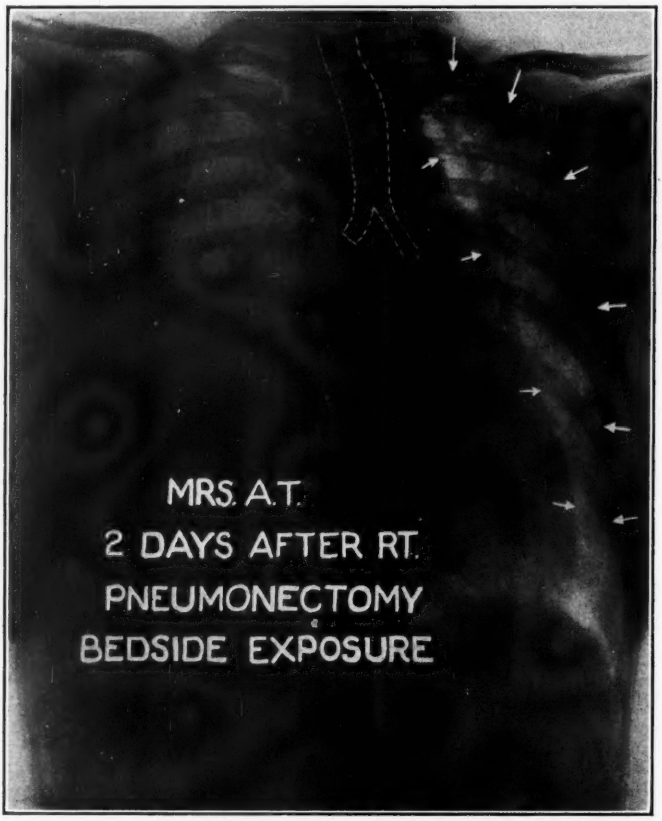


Fig. 3.—Roentgenogram of a patient upon whom a pneumonectomy was performed. During operation the mediastinum deviated to the left. The roentgenogram illustrates how little breathing space this patient had. High concentrations of oxygen were administered with cyclopropane. See Fig. 4.

a compressible, cyclic, hydrocarbon gas with the empirical formula $C_3H_6$, and may be administered by means of the ordinary gas machine. Cyclopropane is a very powerful anesthetic agent, giving a depth of anesthesia approaching that of ether and being capable of administration in concentration of 20 per cent or less, with 80 per cent or more of oxygen, thus doing away with any danger whatever of anoxemia. It is obvious

that an anesthetic agent which is effective in such a low concentration needs very little absorptive surface in order to reach a sufficiently high concentration in the blood to maintain surgical anesthesia.

We have repeatedly anesthetized patients with vital capacities limited to one-fourth their estimated normal (900 to 1,400 c.c.). In all these patients, the venous and arterial bloods are indistinguishable during operation. This hyperoxygenation of the blood is accomplished with

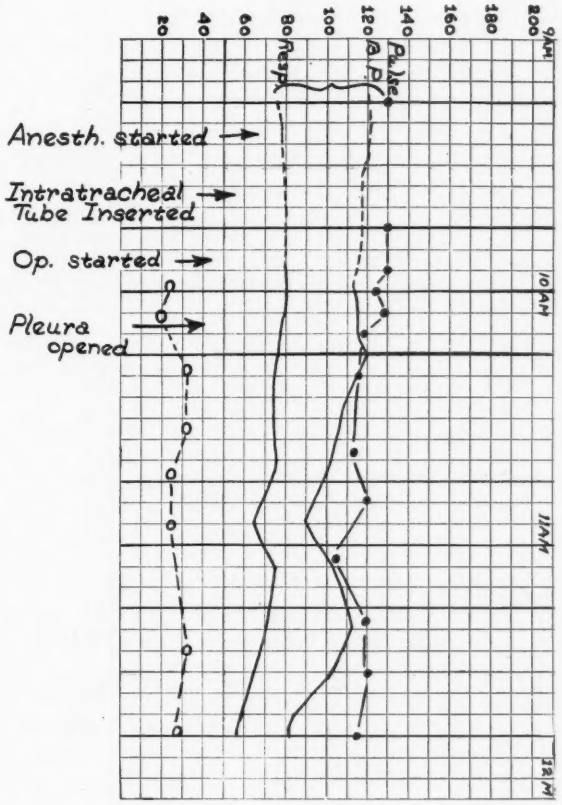


Fig. 4.—Anesthesia chart. Operation, complete right pneumonectomy. Intratracheal cyclopropane anesthesia was given using high concentrations of oxygen.

quiet, shallow excursions of the thoracic walls. In Fig. 3 is shown the chest roentgenogram and in Fig. 4 the anesthesia chart in a pneumonectomy case (Mrs. A. T.) which illustrates how small the functioning lung may be and still maintain oxygenation adequately throughout the period of anesthesia. The roentgenogram was taken two days after operation and shows the remaining left lung limited in volume by a displaced mediastinum toward that side. Throughout the operation, the venous

and arterial bloods grossly gave the same oxygenated appearance. The patient subsequently was anesthetized on two occasions for thoracoplasty at which time the vital capacity was 900 c.c.

Therefore, since an adequate oxygenation of the blood can be maintained regardless of a markedly limited lung volume and since this can be accomplished with quiet, shallow respiratory movements, the great advantage of cyclopropane becomes obvious. There is no doubt but that anoxemia during the course of an operation has been responsible for many of the difficulties of the anesthetist and of the thoracic surgeon. Anoxemia, cyanosis, carbon dioxide accumulation, respiratory center stimulation, irregular and struggling respiratory movements, and a rising pulse have been frequent occurrences with the ordinary types of anesthesia.

The recovery period from a cyclopropane anesthesia is rapid, varying usually from three to ten minutes until consciousness is regained. The cough reflex returns with equal rapidity. Nausea and vomiting

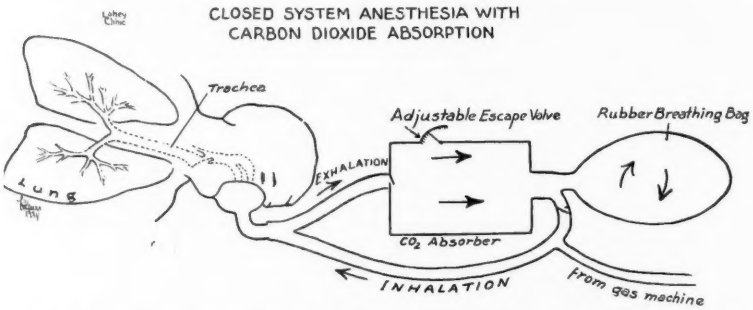


Fig. 5.—Diagram illustrating the principles of the carbon dioxide absorption method of administering an anesthetic mixture. A closed system is advantageous for intrapleural operations. The withdrawal of carbon dioxide from the closed system aids in the production of quiet respiratory movements. The more gentle the breathing during the induction and course of the anesthesia, the less trauma to the diseased lung.

occur in approximately one-fourth of the patients in the first three minutes, but only one-tenth of the patients have subsequent nausea. Cyclopropane, therefore, compares favorably with other inhalation gases in regard to postoperative nausea and vomiting.

Cyclopropane has the disadvantage of being both inflammable and explosive when mixed with almost all proportions of oxygen. Waters[5] has found its hazard in this regard comparable to that of ethylene. If the same precautions are used in its administration, there is little practical danger. These precautions call for an entirely closed system and avoidance of the static spark.

### CARBON DIOXIDE ABSORPTION TECHNIC

The carbon dioxide absorption technic is used almost exclusively for all inhalation anesthesia given in the Lahey Clinic. The accompanying

diagram (Fig. 5) illustrates the essential principles of the carbon dioxide absorption method. The diagram shows how the intrapulmonic pressure in a closed system is under the direct control of the anesthetist. The advantages of this technic are:

(a) A quiet type of respiration without the forceful movements of the thoracic cage caused by carbon dioxide accumulation.

(b) The explosive hazard is greatly minimized by preventing the liberation of gases in the operating room.

(c) Economically this method has a very distinct advantage. The same anesthetic mixture is rebreathed throughout the entire operation, oxygen being added at a rate sufficient to satisfy the metabolic needs of the body. The carbon dioxide is extracted by passing the gases through soda lime.

(d) The intrapulmonic pressure is at all times under the control of the anesthetist as it is in any entirely closed system. The danger of overdistention of the lungs by pressure upon the bag can be eliminated by having in the gas circuit an escape valve adjustable to different degrees of pressure.

We believe, therefore, that in major thoracic procedures the high percentage of oxygen which is used with cyclopropane and the advantages of the carbon dioxide absorption method combine to produce an anesthesia which most closely approaches the ideal.

## CONDUCT OF ANESTHESIA

In general, the conduct of anesthesia in chest surgery is similar to that in general surgery, yet it differs in certain respects. These differences are very important and may result in serious consequences if the anesthetist and surgeon are not prepared to deal with them adequately. Some of the problems of the thoracic anesthetist should be considered.

1. Accidental opening of both pleural cavities makes spontaneous respiration impossible and necessitates immediate artificial respiration. This can best be accomplished by rhythmic manual pressure on the rubber breathing bag containing the anesthetic mixture. This is very easily done and may be kept up indefinitely if an inhalation anesthetic is being administered by means of an entirely closed system. Seven to eight millimeters of mercury pressure is sufficient to prevent collapse of the lung, and a pressure of 20 to 22 mm. should not be exceeded. The need for positive pressure when the pleural cavity on only one side has been opened, we feel has been greatly exaggerated. In our experience, in such instances, it has rarely been necessary to add to the pressure in the closed system. Positive pressure is needed, however, when the pleural cavity is opened in the presence of a contralateral pneumothorax. Sudden and accidental pneumothorax on one side may cause a patient to go into collapse from a quick shifting and subsequent flapping of the

mediastinum. This does not occur if the closed system is being employed at the time the opening is made, and if immediate positive pressure is established.

2. The compression of the lung during and after thoracoplasty may be sufficient to force enough fluid or purulent material into the bronchi and trachea to cause asphyxia if such material is aspirated into the dependent lung. Hemorrhage into the bronchus during the course of an operation may be of such magnitude that the patient virtually drowns in his own blood.

The frequency with which these conditions occur makes it advisable that fairly strong suction be available at all times; in fact, a suction apparatus with a number sixteen French catheter is a part of the routine operating room equipment for all thoracic cases in the Lahey Clinic. A catheter of this size is convenient for nasal passage and is also satisfactory for pharyngeal aspiration. If an intratracheal tube is in place, this catheter can easily be passed down within the lumen of the intratracheal tube, and any fluid which accumulates in the trachea or primary bronchi can be aspirated. If an intratracheal tube is not in place, it should be immediately inserted when the first evidence of an accumulation in the air passages occurs.

3. Respiration may become obstructed and thus a serious emergency be created with which the anesthetist must be prepared to cope. It can usually be relieved by the use of nasal or oral breathing tubes. If, however, the obstruction is lower down, an intratracheal catheter should be inserted. Due to the fact that the position of the patient on the operating table for most thoracic operations is such that the insertion of an intratracheal catheter is quite difficult, this should always be done before the operation starts if for any reason the anesthetist suspects that a serious obstruction may develop. In cases in which one or more lobes of the lungs are to be removed, we feel that an intratracheal catheter should be routinely used. We also routinely insert an intratracheal catheter in all cases of bronchiectasis and lung abscess when a general anesthetic is desired. It can be used to advantage in some tuberculous subjects for thoracoplasty when excessive secretions are present and a general anesthesia is necessary. In the average thoracic case, more particularly thoracoplasty, serious obstruction is not in our experience sufficiently common to warrant the routine use of an intratracheal breathing tube. We have found the flexible metal catheter designed by Flagg and later modified by Woodbridge[6] of this Clinic to be very satisfactory in thoracic cases. Because of the combination of its extreme flexibility and resistance to lateral compression, there is no danger of its kinking during the process of placing the patient into position for the operation after the catheter has been inserted.

Concerning preoperative medication, Waters[5] has pointed out that cyclopropane, in contradistinction to ethylene and nitrous oxide, is not a respiratory stimulant. Hence, preoperative medication of a respira-

tory depressant nature, such as the opium derivatives, should be used in much smaller dosage than in preparation for anesthesia other than cyclopropane. In addition, cyclopropane is a sufficiently strong anesthetic agent to maintain surgical anesthesia of sufficient depth without the aid of heavy preoperative medication. Since scopolamine is not a respiratory depressant, it is unnecessary to decrease the dosage of this drug proportional to the decrease in opiate dosage. Our average dosage at the present time ranges from $\frac{1}{32}$ to $\frac{1}{64}$ grain of dilaudid (dihydromorphinone hydrochloride) and $\frac{1}{150}$ grain of scopolamine hydrobromide given subcutaneously one hour before the operation.

## SUMMARY

A general discussion of the problems of anesthesia peculiar to thoracic surgical conditions has been given. Factors which reduce lung volume and limit absorption of anesthetic mixtures have been considered. Poor tolerance by the average thoracic patient for anoxemic states has been pointed out. The great failing of most anesthetic mixtures in providing high concentrations of oxygen has been discussed. Reasons are given to show that cyclopropane administered by the carbon dioxide absorption method more nearly meets the ideal in thoracic anesthesia than any of the other available anesthetic agents. Some technical problems peculiar to anesthesia for thoracic surgery have been considered.

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# TECHNIC OF EXPERIMENTAL CORONARY SINUS LIGATION*

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IT IS now generally believed that the pain of angina pectoris is due to myocardial ischemia. The ischemia may be due to sclerotic coronary artery narrowing or to occlusion which may be followed by thrombosis. The most frequent site for the occurrence of this lesion in the human heart is the left anterior descending branch approximately 2 cm. below the ostium of the left circumflex coronary artery.

In 1921, one of us (L. G.)[1] described three vascular mechanisms in the blood supply to the human heart which probably serve as compensatory means of warding off the results of coronary artery narrowing or occlusion. These consist of (a) intramyocardial anastomoses; (b) pericardial fat vessels; (c) anastomoses between these two and extracardiac vessels. Recently attempts have been made by Beek, Tichy and Moritz[2] and by Robertson[3] to increase the blood supply to the heart by producing pericardial adhesions. The experimental procedures employed by these authors appear to be quite extensive. Moreover, since there was produced simultaneously a gradual occlusion of coronary branches over a considerable period of time, it is difficult to evaluate their results.

Basing our views on anatomic and clinical observations, we believed that an increase in intramyocardial collateral circulation would probably follow coronary sinus obturation. The purpose of this report is to describe a relatively simple technic for performing coronary sinus obturation, which appears to produce a rapid and dramatic increase in the extent of the coronary tree of the dog's heart (Figs. 1 and 2).† The dilatation of the intramyocardial collateral circulatory channels thus produced is apparently so extensive and abundant that in the majority of dogs' hearts prepared in this manner it becomes difficult or impossible to induce infarction by subsequent acute occlusion (division between ligatures) of the left anterior descending branch 2 cm. below the aortic ostium of the left coronary artery. On the other hand, without such preliminary coronary sinus ligation, occlusion of the left anterior descending branch at the site indicated almost invariably produces extensive infarction in the dog's heart. The results of these experiments have been reported by us elsewhere.[4, 5]

*From the Laboratories of The Mount Sinai Hospital.
Aided by grants from the Lucius N. Littauer and Walter W. Naumburg Funds.
Received for publication July 15, 1935.

†This is visualized by the injection technic described by Gross (A New and Improved Injection Apparatus. J. Lab. and Clin. Med. 13: 257-262, 1927). See also reference 1.

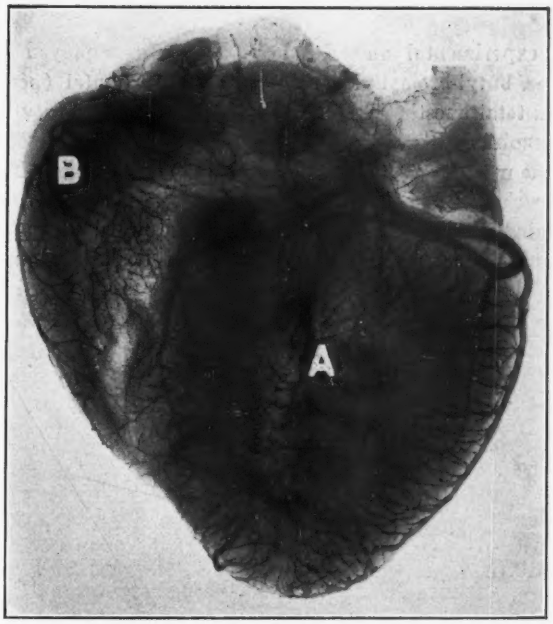


Fig. 1.—Injection of coronary arteries in normal dog's heart showing extent of the vascular bed. *A*, left ventricle; *B*, right ventricle.

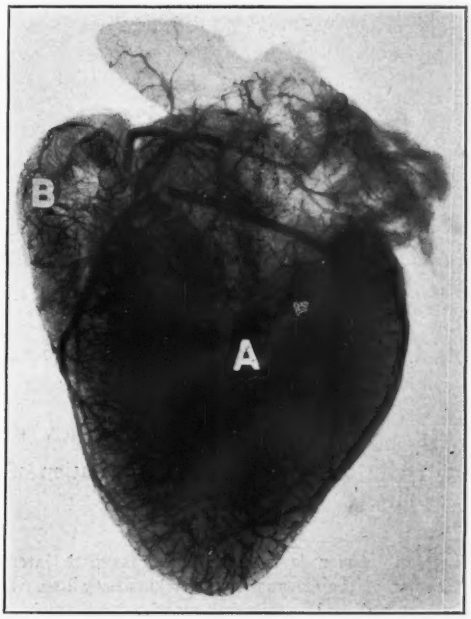


Fig. 2.—Injection of coronary arteries in dog's heart following coronary sinus ligation. Note enormous increase in the vascular ramifications. *A*, left ventricle; *B*, right ventricle.

In the experimental animal (dog), we have employed pernoston (sodium sec. butyl-bromallyl barbiturate) and nembutal (pentobarbital sodium) as total anesthetics. As soon as the thoracic cavity is entered, artificial respiration is administered (positive pressure). This is provided by the usual type of differential insufflation machine. The amount of aeration should be carefully controlled. The more common extreme to be avoided is hyperventilation with its untoward physiologic effect and the added difficulty of displacing the distended right lung from the operative field. The other extreme is insufficient aeration which not only

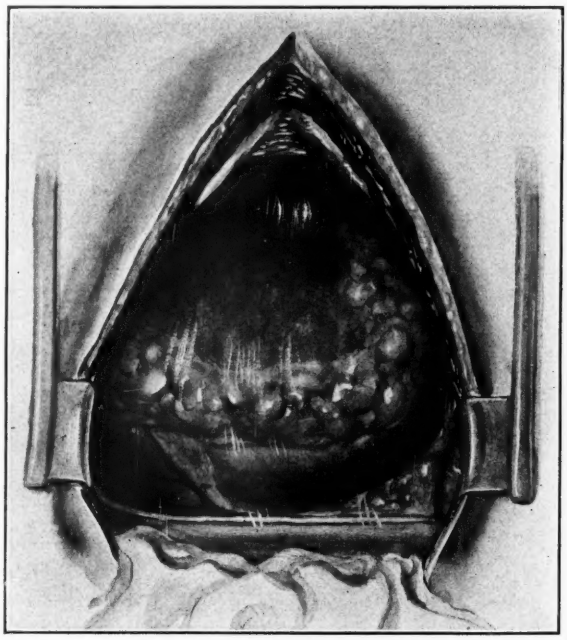

Fig. 3.—Exposure of dog's heart through the right fifth intercostal space. Dotted line indicates location of pericardial incision.

asphyxiates but, due to the low intrapulmonary pressure in the left lung, also allows the heart to sink into a less accessible portion of the thoracic cavity.

The details of the operation can be readily appreciated if described in four stages, arbitrarily termed exposure, visualization of the coronary sinus, ligation, closure.

## EXPOSURE

*Procedure.*—The skin incision is made in the right fifth intercostal space, extending from the border of the sternum to the midaxillary line. It is then carried down through the pectoral and intercostal muscles and fascia to the posterior intercostal membrane. In order to avoid injury to the lung the pleural cavity is

bluntly entered. Simultaneously, insufflation is begun. The pleural incision is extended to the full length of the wound, and an automatic rib spreader is inserted. The middle and lower lobes of the right lung are slowly and thoroughly deflated by manual pressure and are then covered with a large moist pad. The pericardium is thus fully exposed. At this stage the operative field appears as in Fig. 3.

*Comment.*—The intercostal approach is employed on an empiric basis. We have learned that it offers, for our particular purpose, a most satisfactory exposure with little shock. In order to minimize the manipulative difficulties due to the rather narrow wound, that intercostal space

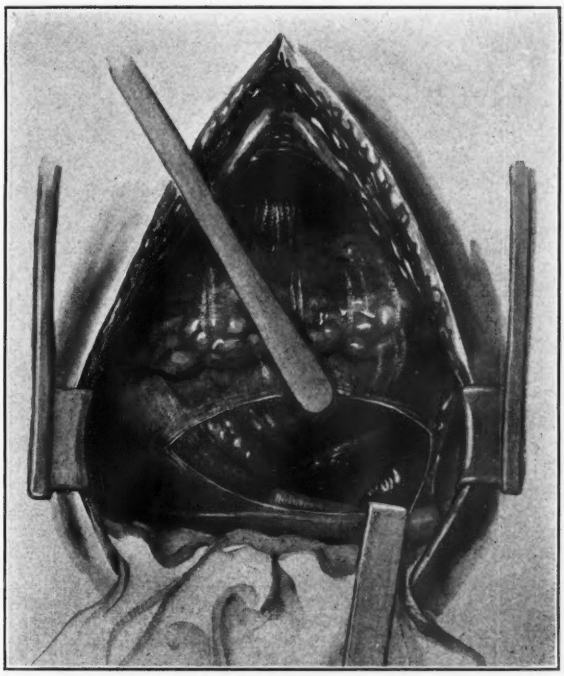

Fig. 4.—Exposure of inferior vena cava and coronary sinus through incised pericardium. Lower retractor overlies the inferior vena cava. Upper retractor is rotating the heart slightly. This exposes the coronary sinus which is seen partially surrounded by fat tissue in the atrioventricular sulcus.

should be chosen which lies just below (inferior to) the atrioventricular sulcus of the heart. In the dog this happens to be the fifth space. The right side is chosen because ligation at the terminus of the coronary sinus in the dog's heart is simple to perform through this approach. Another advantage of this technic is the avoidance of the internal mammary vessels.

### VISUALIZATION OF THE CORONARY SINUS

*Procedure.*—An incision, 6 cm. long, is made in the pericardium, parallel to and 0.5 cm. anterior to the phrenic nerve. It should extend 1 cm. cephalad to the

atrioventricular sulcus. A blunt, flat-bladed retractor is applied against the right ventricle in such manner as to push it slightly away from the wound and, at the same time, to rotate the heart anteriorly a few degrees. A small, hooked retractor is then inserted in the inferior angle of the pericardial wound to depress the lower leaf and so expose more of the posterior aspect of the heart. By appropriate manipulation of these instruments, the terminal portion of the coronary sinus can be brought into view. The exposure can be improved to that represented in Fig. 4, by traction on the reflection of visceral pericardium that lies, posteriorly, in the angle between the coronary sinus and the inferior vena cava. This can be done with an artery forceps (not shown in the illustration).

*Comment.*—The coronary sinus lies on the posterior aspect of the base of the heart. The pericardial incision is therefore located as near the phrenic nerve as is consistent with easy closure. The flat retractor also serves to depress the overhang of the right border of the heart. The angled retractor need not exert any pressure on the inferior vena cava. The central point, anatomically, of this cardiac area is a small but constant, clearly visible depression marking the termination of the coronary sinus as it turns in to empty into the right atrium. We have termed it "the dimple," since it makes a puckering of the visceral pericardium. On the other side of the dimple lies the atrial opening of the inferior vena cava.

### LIGATION

*Procedure.*—A fine, blunt needle is passed deep to the coronary sinus in an oblique direction. The point of entry should be located on the atrial side about 1 cm. from the dimple, and the point of emergence should lie on the ventricular side, 0.5 cm. from the dimple. The location of the sinus in the atrioventricular sulcus, and the path of the needle through the myocardium are portrayed in the inset of Fig. 5. By observing the precaution of the oblique direction, the terminal portion of the circumflex branch of the left coronary artery is avoided. We have used No. 4 white silk for the ligature.

*Comment.*—This maneuver was attained through a process of gradual technical evolution. Our original attempts at transatrial plugging of the sinus opening and external painting with silver nitrate were soon abandoned. The first effective procedure consisted in complete dissection of the terminal half inch of the sinus. This was obviously too delicate and too tedious a procedure. There was also the added necessity of separately identifying and excluding the terminal portion of the left circumflex artery. Due to the length of time which was required (one and one-half hours on an average), and the necessarily prolonged tilting of the heart, the operative mortality was 60 per cent. The needle technic is easier and quicker. It also seems to constitute less of a shock to the animal as indicated by a lowering of mortality to 20 per cent.

Avoidance of tilting the heart appears to be an important factor in lowering the operative death rate. It has been our experience that the heart will withstand a good deal of operative trauma, bleeding and prolonged traction to either side. With any angulation about the trans-

verse axis (i.e., tipping anteriorly of the ventricles on the fixed base), however, the following untoward sequence of events takes place: There is noted first a dilatation of the right atrium which is soon followed by a marked tachycardia. If not allowed to recover, this goes on to a terminal auricular fibrillation.

The needle we employ is a fine intestinal needle with the point smoothly rounded off. It does not lacerate the constantly moving myocardium, leaves a narrow tract, and inflicts minimal damage on the rich myocardial vasculature. We have deliberately entered the atrial chamber

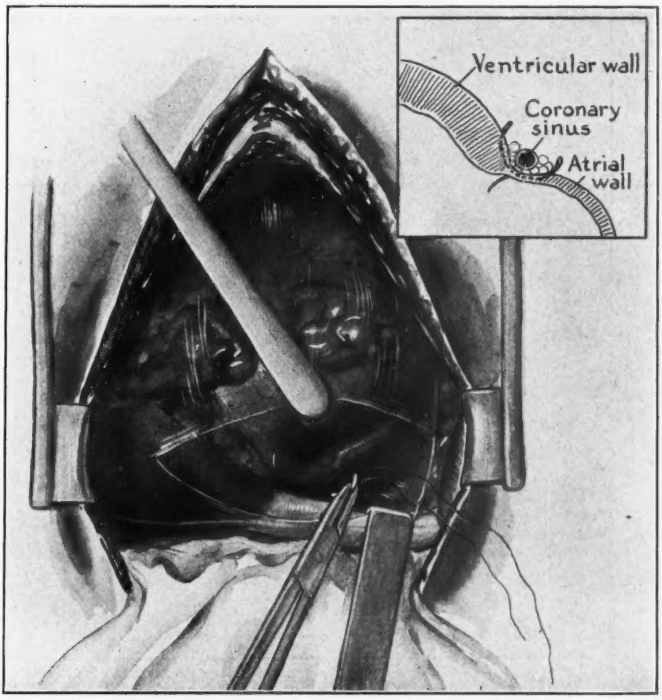


Fig. 5.—Curved needle passed under the coronary sinus near its termination in the right auricle. Insert shows position of needle with respect to atrial and ventricular walls and the coronary sinus.

in several dogs with this needle and find that little or no bleeding occurs. It is preferable to take a larger bite and make certain of total sinus ligation at the apparently small risk of needling the atrium, than to tear the sinus.

## CLOSURE

*Procedure.*—The pericardium is closed with a fine running suture, a small aperture being left at the inferior angle as a prophylactic against tamponade. Two heavy pericostal sutures are first placed to facilitate the pleurointercostal closure, which is done with a running suture. This is followed by muscle and skin closure, silk being used throughout.

*Comment.*—After the coronary sinus ligature is tied, there is first noticed a definite slowing of the heart rate. The contractions also appear to be more forceful. This is not due simply to manipulation because, if the coronary sinus is torn or a loose ligature is applied around it, the rate either remains unaltered or becomes increased. The second change noted is a definite and gradually increasing cyanosis of the entire heart (Fig. 6). The surface veins and coronary sinus dilate markedly as soon as the ligature is tied, but the color change of the myocardium is noted several minutes later. The change is from the

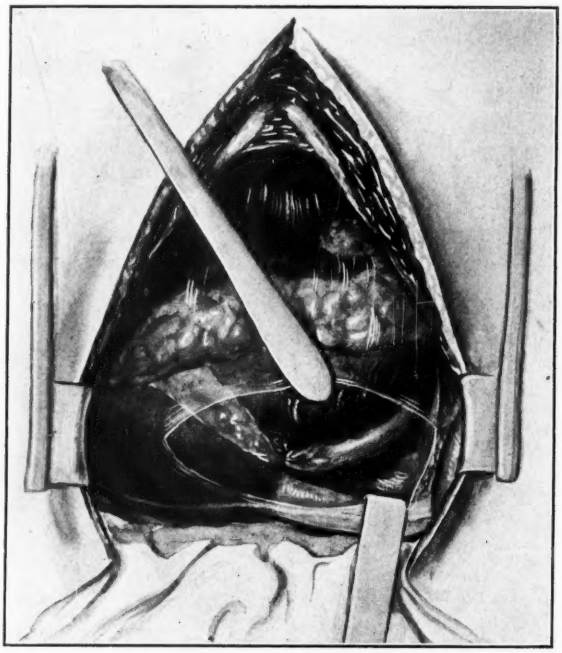

Fig. 6.—Appearance of operative site several minutes after total ligature of the coronary sinus. Note ligature in place at the region of the dimple. Note also engorgement of the coronary sinus and change in color of the myocardium.

normal reddish brown appearance of the ventricles to a true mahogany hue. We have observed that this persists for at least one month, postoperative. These changes in color and rhythm confirm the presence of a complete coronary sinus occlusion.* At reoperation, the only site of adhesion that we have noted to occur with any frequency is along the line of pericardial closure. The site of ligation is covered with visceral pericardium within one week of the time of operation.

*Certain characteristic electrocardiographic changes associated with coronary sinus occlusion are described in reports which will appear in Proc. Soc. Exper. Biol. & Med., and in the American Heart Journal.

SUMMARY

Coronary sinus occlusion in the dog's heart produces a rapid increase in the extent of the coronary tree and in the intramyocardial collaterals as determined by the injection technic. In the majority of dogs' hearts thus prepared it is difficult or impossible to induce infarction by subsequent acute occlusion (division between ligatures) of the left anterior descending branch approximately 2 cm. below the aortic ostium of the left coronary artery. A description is given of the technic which we have found most satisfactory for the production of coronary sinus occlusion in the dog's heart. We believe that the method, with variations in technic in keeping with a somewhat different anatomic arrangement, may be applicable to the human heart and have therefore presented the procedure in this report.

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# RIB FRACTURE FROM COUGH

## Report of Twelve Cases

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FRACTURE of ribs from coughing or sneezing, in the absence of bone pathology, is not of common occurrence. However, the attitude occasionally encountered that such fractures are either impossible or so rare as to constitute a "medical rarity" is probably not altogether justified. It is doubtless because of this attitude that the condition is so little known through failure to watch for this type of fracture. As early as 1862, Gurlt[1] in his treatise on fractures had collected fourteen cases of spontaneous fractures due to cough. Since that time additional instances have been added to the literature by Bähr,[2] Tunis,[3] Atkinson,[4] Seilin,[5] Pospischill,[6] Webb and Gilbert,[7] Kleiner,[8] Palfrey,[9] Wahl,[10] Halliwell,[11] and Howson,[12] each reporting from one to twelve personally observed cases and bringing the total to ninety cases. Thirteen of these were due to muscular action other than that involved in coughing or sneezing. During the past three years rib fractures have been looked for as a part of the routine interpretation of chest films at the Olive View Sanatorium. Among approximately two thousand admissions, eleven instances of fracture involving from one to four ribs have been observed, an incidence of 0.6 per cent. One additional case had been previously diagnosed clinically. Fracture in all twelve cases was unquestionably due to cough. Doubtless, there were other instances which escaped detection due to pleural effusion, thickened pleura, or atelectasis. It is of some importance to realize that these fractures do occur and to be able to relieve the discomfort which they occasion.

Fracture was associated with far-advanced tuberculosis in all but one patient, who had bronchial asthma and bronchitis. Induced pneumothorax was present in four instances and phrenic paralysis in one case. No relation between fracture and these therapeutic procedures could be traced, since fracture occurred impartially on the same and opposite side in the different cases. Nor did the presence of tuberculous involvement in one lung predispose to fracture on the same side, as three of the nine unilateral fractures were associated with tuberculosis in the lung on the same side, three in the lung on the opposite side, two with bilateral tuberculosis, and one with asthma. Of the three patients with fractures on both sides, two had tuberculous lesions in only one lung.

Received for publication, February 18, 1935.

As to the side involved, the figures in this series, admittedly small for statistical purposes, do not agree with those of Tunis. He found, among forty collected cases, no bilateral fractures, ten right-sided fractures, nineteen on the left, and eleven unrecorded. From this predominance of left-sided fractures, he and other writers deduced that the liver affords some protection against fracture on the right side. Of the twelve cases in the series, nine were unilateral and three, bilateral. Of the unilateral fractures, five were right-sided and four, left-sided. Also, of the total of eighteen individual fractures experienced by the twelve patients, nine were right-sided. In the light of these figures, one cannot ascribe much splinting effect to the liver.

The appearance of the ribs was normal in every instance, and healing was fairly prompt, depending on the treatment afforded. There was no evidence of bone atrophy or calcium absorption. The age distribution was from twenty-two to sixty-five years, with an average age of thirty-five years, which is about the average for the sanatorium patients. Pospischill found among a group of children "perhaps a dozen" instances of rib fracture from cough, an incidence of 0.4 per cent. Since all of these were children, apparently the age distribution depends on the type of pathology causing cough. Sex plays no part, as five of the twelve were male, a proportion also observed by earlier writers.

A study of these twelve cases, as well as cases reported earlier, indicates that muscular action is the determining factor in the occurrence of these fractures. External trauma has been eliminated. A typical history is that, during a severe coughing spell, the patient notices a "catch" or "stabbing pain" in a sharply localized area, which he can point out accurately and which later is found to be the site of fracture. The usual signs and symptoms of fracture are elicited.

Kleiner corrects a mistaken impression that childbirth is the cause of fracture. He found only four cases in which the woman was pregnant. In only one of these did the fracture occur during parturition and that was when a spell of coughing came on. In the other three, fracture was the result of cough and occurred earlier in pregnancy.

The position of the fractures is of considerable interest in relation to the mechanism of fracture. Without exception, they were found in a line extending from a point about 4 cm. from the costochondral articulation of the fourth rib obliquely caudad and laterally to the ninth rib in the midaxilla (Fig. 1). In almost all of the reported cases, the fractures are located in the same line. This location corresponds to the heavy muscular attachments of the obliquus externus abdominis, where it interdigitates with the serratus anterior (Fig. 2). From this exact anatomic coincidence, one would suspect, therefore, that either one or the other of these muscles or both were concerned in a causative manner with this type of fracture. The contention of Tunis, Seilin, and others

that contraction of the diaphragm causes the fracture is difficult to accept because the attachments of this muscle do not correspond to the line of fractures.

Evidence from the physiologic aspect points in the same direction and indicates that the muscles of expiration play a causative rôle, an indication which is in agreement with the ideas of Webb and Gilbert. When a patient feels an impulse to cough, he inhales fairly deeply through contraction of the diaphragm and other muscles of inspiration. The inspiratory phase of cough is often rapid, but it does not have a

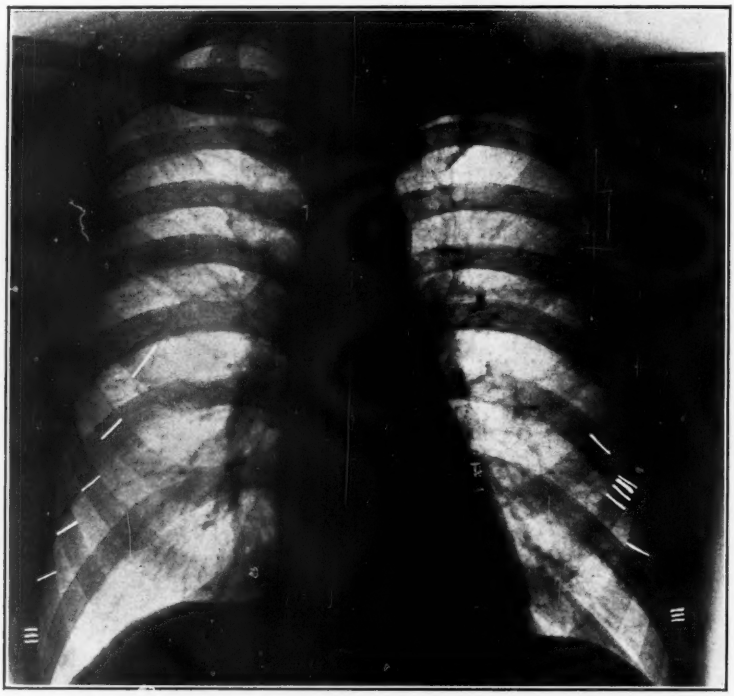

Fig. 1.—The location of the eighteen fractures suffered by the twelve patients is shown by placing marks on a single roentgenogram. Nearly all fractures from cough reported in the literature are in this same location.

violent or spasmodic character. The expiratory phase is initiated, following a momentary apposition of the vocal cords, by strong contraction of two sets of muscles, (1) the internal intercostals, triangularis sterni, serratus posterior inferior and quadratus lumborum and (2) the abdominal group, the external and internal oblique, transverse, and recti muscles. Of the two groups, the latter is more powerful and the pressure of their contraction is transmitted through the now inert diaphragm. With a building up of positive pressure in the chest, the vocal cords

are separated with a sudden dissipation of the positive pressure by rapid egress of air. There are usually several of these expiratory efforts in rapid succession before the next inspiratory phase. The contraction of the expiratory muscles is often sudden and spasmodic and appear much more capable of causing rib fracture than the diaphragm.

Certain considerations suggest, however, that contraction of the abdominal expiratory muscles alone is not the sole cause of fracture and

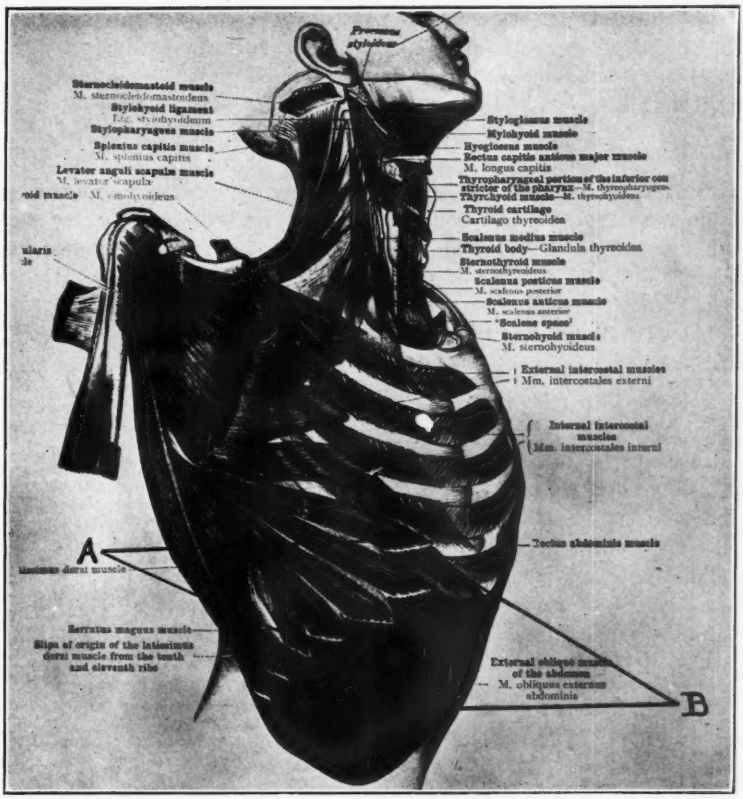


Fig. 2.—The muscular attachments and interdigitations of the serratus magnus muscle, *A*, and the external oblique muscle of the abdomen, *B*, correspond exactly to the line of fractures as shown in Fig. 1. (From Toldt's Atlas of Human Anatomy, Vol. 1, p. 277.) By permission of The Macmillan Company, publishers.

that Tunis was correct in his opinion that opposing action of two sets of muscles may be a necessary factor. Seilin's patient had an attack of coughing while lying on her left side and at the same time closing a near-by window. The right-sided fracture occurred while she was simultaneously coughing and forcibly adducting her right arm. Atkinson's patient was in the act of hanging a heavy overcoat on a hook when an

attack of coughing occurred, with a fracture resulting. One of my patients was lying in bed, propped up on his elbows, when an attack of coughing came on. Fracture occurred at this time. Two others were raising themselves up in bed while coughing. Another, before admission to the sanatorium, was raising a folding bed when a coughing spell came on. In all six instances the muscles attached to the shoulder girdle and to the chest wall were tense at the same time that the abdominal muscles were in strong contraction in the expiratory phase of coughing. It seems possible that contraction or tension of the shoulder girdle muscles, particularly the serratus anterior, exerting a pull laterally and cephalad, as opposed to the simultaneous pull of the abdominal muscles mesiad and caudad, may be the determining factor in this type of fracture. If more careful histories could have been taken in all of these cases at the time of the fracture, rather than weeks or months later when the patient has forgotten details, doubtless the factor of opposing action of these two sets of muscles would have been given even greater confirmation. Wonder is expressed by some writers that such long, thin bones as ribs are not more often fractured by muscular action. The above theory would seem a possible explanation. Coughing is common enough in pulmonary disease, but the added factor of opposing action of muscles may not be so common.

## SUMMARY

Twelve cases of fracture of from one to four ribs from cough, observed during a period of three years, are reported. The fractures all occurred in a location corresponding to the attachments of the obliquus externus abdominis and serratus anterior muscles. Anatomic and physiologic evidence indicates that many of these fractures are due to opposing action of these muscles. No causative relation could be traced to sex, age, location of pulmonary pathology, or to the liver as a protective factor. With an incidence of 0.6 per cent, this type of fracture must be classed as uncommon, but realization that it can and does occur should lead to a readier recognition.

Since writing this article, I have observed ten additional cases of rib fracture caused by cough. These occurred among approximately one thousand admittances. With one exception, in which the first rib was fractured, the fractures occurred in the area described in the above article.

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# PHARYNGOCELE (PULSION DIVERTICULUM)

## Report of a Case

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THE patient was E. S., male, fifty-five years old, who was sent to me by Dr. John W. Vollmer of Norwalk, Conn. The early past history is irrelevant.* In 1926 or thereabouts, he began to notice a gurgling in his throat, especially at night, and later food and saliva in increasing quantities were disgorged. The trouble was progressive.

I first saw him on Nov. 4, 1935. He then went to the Out-Patient Department of the New York Hospital, where a diagnosis of pulsion diverticulum was made. The sac was a large one, and extended to about ½ inch below the upper limit of the gladiolus sterni. There was a slight cough, and a suspicion of right bronchial disorder probably because of spilling from the diverticulum. He had lost about 35 pounds in weight; his height was 5 ft. 5 in., and he weighed but 100 pounds. I had been instructed by another patient with this disease that if a coarse meal were taken the diverticulum would be filled by it, and afterward a regular meal would pass by the opening and enter the stomach. This patient would then drink water, and both manually and by voluntary expulsive efforts the diverticulum would be emptied. Mr. S. gained 8 pounds in less than three weeks by this regime, and felt much better. His blood pressure was 90/60.

It had been my intention to perform a preliminary gastrostomy, but on account of this gain in weight I decided that it would not be necessary. An x-ray picture made at the New York Hospital is shown in Fig. 1. The diverticulum is filled with barium mixture. In order to gain a general idea of the thickness of its walls, I ordered a film in outline by having the patient insert a Levin tube into the diverticulum through the mouth (Fig. 2).

The operation, first stage, was performed at the Mount Sinai Hospital on Dec. 28. Dr. Branower administered avertin and a little nitrous oxide and oxygen; Dr. Touroff rendered valuable advice and assistance. Dr. Rudolph Kramer passed the esophagoscope which dropped easily into the diverticulum, but there was great difficulty in inserting it into the esophagus itself, because the opening of the diverticulum was much wider than the normal esophagus.

Procedure.—An incision was made from beneath the angle of the jaw in front of the left sternomastoid muscle down to the jugulum, and was later continued upon the manubrium for a very short distance. The sternomastoid and great vessels were retracted outward, and the diverticulum was found; but in order to identify it, Dr. Kramer passed the esophagoscope, and a light within this instrument greatly facilitated the orientation. Blunt dissection, mostly with the fingers, using the esophagoscope as a guide, finally freed the diverticulum. Its walls, as was suggested by the picture shown in Fig. 2, were thick, tough, and muscular. The intrathoracic manipulation to raise the sac into the neck was difficult and delicate. There was tough, fibrous and muscular adhesion to the arch of the

Read before the New York Society for Thoracic Surgery with presentation of patient, Feb. 28, 1936.

Received for publication, March 6, 1936.

*The patient's gallbladder had, however, been removed in 1931, but no stones were found. C. T. Sturgeon, J. A. M. A., Feb. 2, 1929, reported a case of esophageal diverticulum in which gallbladder disease with stones was a complication. It is of course possible that my patient's symptoms may have been mistaken for gallbladder disease.

aorta, and I feared the presence of a thyroidea ima artery. Therefore, this band was cut between two ligatures. The sac was then free, and could be drawn out of the wound.

I was disappointed to find that the opening into the gullet was even larger than I had imagined from the endoscopic findings. The operation had been tedious, and the patient's pulse began to be a bit rapid; so, being warned by Dr. Branower, I decided upon a two-stage procedure.

The diverticulum was therefore laid upon the outside of the neck in a vertical position, its opening at the lowest point for drainage into the esophagus, and was held there by two catgut sutures to the skin just below the ear. A bit of folded rubber dam was laid into the mediastinum as far as the diverticulum had extended, emerging through the lower part of the skin wound. The remainder of the wound was closed with silkworm-gut sutures and metal clips, with one chromicized catgut suture passed through the wall of the diverticulum near its neck and through the sternomastoid muscle. It was impossible to pass a Levin tube

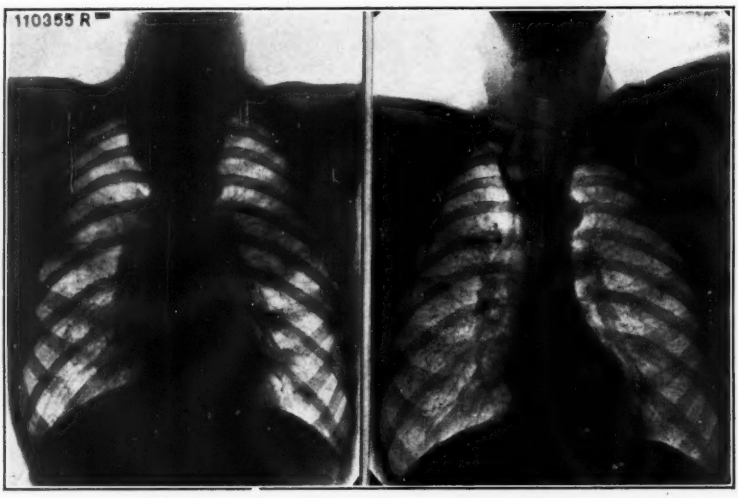


Fig. 1. Fig. 2.

Fig. 1.—Diverticulum filled with barium mixture. Faint opacities in the lung fields indicate injection probably caused by bronchial infection.

Fig. 2.—Levin tube inserted through the mouth demonstrates relation of the diverticulum to adjacent structures. Fluid level of residual barium mixture is seen.

into the stomach through the nose in the usual manner; therefore it was inserted through the esophagoscope and was later withdrawn through the right nostril so as to make wearing it more comfortable. A light gauze dressing was applied over a few layers of vaseline gauze upon the wound and upon the diverticulum. The patient's condition at the end of the operation was satisfactory.

He was fed through the tube but could not swallow even a tiny bit of liquid by mouth. Twenty-four hours after operation his blood pressure had risen to 112, then rapidly dropped to its preoperative level of 92/60. There was slight cyanosis. He had received morphine only twice, and then for intense discomfort, not pain. Digitalization was carried out. Considerable quantities of water were administered.

On December 31 I found the right lower lobe apparently consolidated or filled with secretion. Clinically there was a bronchopneumonia. All attempts to swallow were at once discouraged, and high caloric fluids were given by tube. Dr. A. Penner

was called to take charge of the medical aspect of this important complication. Suddenly, at 11 o'clock, December 31, three hours after a hypodermatic injection of ⅙ gr. of morphine, the patient went into profound collapse; pinpoint pupils, Cheyne-Stokes respiration, pulse extremely rapid, and heart fibrillating. Patient was unconscious. An hour later when I saw him he appeared to be moribund. One seventy-fifth gr. of atropine was at once administered, and twenty minutes later 1/150 gr., and this was repeated a short time afterward; but there was no change in the pupils. The skin, however, which had been clammy, became a little drier. An oxygen tent was installed, and the next morning the pupils were large enough to react to light. The patient was now conscious, and able to speak. The tent was employed for four days. Expectoration was free, but swallowing liquids produced strangling and coughing for more than a week. I thought it possible that the traction upon the diverticulum had angulated the esophagus, but this could not be proved, since loosening the traction did not bring relief. A bedside x-ray picture revealed a bronchopneumonia of the right lower lobe, and a smaller patch in the left chest.

Fig. 3.—See text.

On January 2, 1936, the clips and sutures were removed—apparently primary union. The rubber dam drain had been taken out during the acute dyspneic attack, but the wound looked perfectly aseptic, and there was no discharge.

Not until January 9, thirteen days after the operation, was the patient well enough to sit out of bed part of the time. There were still cough and expectoration, but the strangling on swallowing was almost gone. The sputum became rather profuse—3 to 4 oz. in twenty-four hours—but this gradually disappeared. A photograph was made, and is shown in Fig. 3. The diverticulum, which had been drawn up almost to the ear, was now held up by a suture passed through its wall and hooked over the left ear. The mass had shrunken to about one-third its former size, and its walls had become so thick that it felt almost solid. Sixteen days after the first operation, on January 13, using local anesthesia with novocaine and adrenalin, I extirpated the diverticulum.

The wound had to be reopened through its entire length, but the mediastinum had become thoroughly walled off. With blunt dissection the sac was separated down to the esophagus, and in order to make sure of orientation a large-size ordinary stomach tube was passed down the esophagus through the mouth. The neck of the diverticulum was very large and thick. I exposed the mucosal tube by cutting through the muscular layers surrounding it. This mucosal tube was then transfixed and tied with a rather heavy silk ligature. The diverticulum was then cut away and the mucous membrane stump touched with pure phenol. A few chromicized sutures were passed through the muscular wall of the diverticulum, which had been left sufficiently redundant, and these were tightened while the mucosal stump was pushed into the esophageal lumen. These chromicized sutures were then tied so that there was a good, heavy layer of muscle over the mucosal stump.

Leakage did not begin until six days later, but it has never been great enough to cause anxiety. The wound was closed by strapping with plaster. From that

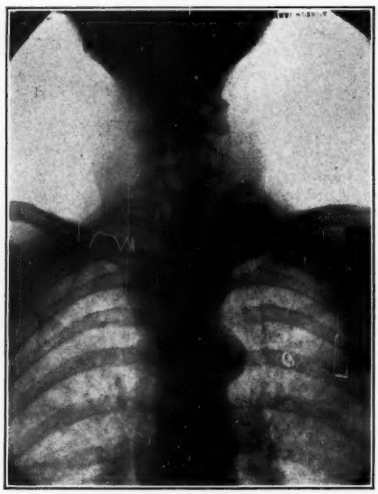

Fig. 4.—X-ray film thirty days after operation. Some irregularity of outline, but no obstruction seen.

time on, recovery has been uneventful, but a tiny drop of water would leak out on swallowing, and the wound has only recently been dry. The patient has gained in weight, almost a pound a day. His general condition is excellent. His voice, probably because of irritation of the recurrent laryngeal nerve, continues even now to be high pitched. An x-ray film with heavy barium was made thirty days after operation, revealing some irregularity in the outline of the esophagus below the level of the cricoid cartilage, but no obstruction was visualized (Fig. 4).

## CONCLUSION

The type of this operation is that described by Chevalier Jackson and Thomas Shallow in *Annals of Surgery*, January, 1926. Here a number of cases are reported, and bibliographical references will be found. It was shown that some postoperative external leakage may be expected in these cases, and it was also well demonstrated to me that, for safety's sake, a two-stage operation is advisable.

# CHYLOTHORAX DUE TO BULLET WOUND OF THORACIC DUCT AND SYNDROME OF TRAUMATIC CHYLOTHORAX*

## Report of Case, and Seven Cases From the Literature

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CHYLOTHORAX resulting from trauma is a rare condition and even more rare when due to a bullet. Because of its infrequency there has been insufficient experience to determine the therapeutic indications. The case here presented is the eighth to be reported due to a bullet and has some outstanding features not found in any other case of traumatic chylothorax, although at the same time it confirms observations made before.

The first authentic case of chylothorax due to bullet wound was reported in 1904 by A. Dietze. His patient was a man, aged thirty-nine years, who attempted suicide. The bullet entered the cardiac area in the sixth interspace, 7 cm. from midline on a level with the xyphoid. No untoward symptoms were noticed until the patient became dyspneic on the third day, and the pulse became irregular. By the sixth day the fluid in the right chest had become significant. On the evening of the seventh to eighth day, the dyspnea was so great that the patient had to sit up to breathe. On the tenth day, because the patient became pulseless and the dyspnea was worse, an aspiration of the right chest was done; 1,500 c.c. of chocolate colored fluid were obtained and thought to be blood and pus. The specific gravity was 1.016. No leucocytes were present, however. Patient's condition improved. After the fluid stood twenty-four hours it separated into three layers: the bottom, red like blood; the middle, yellowish gray; the top, white like cream with fat droplets. Therefore the diagnosis was changed to chylothorax. Three days later, because the patient again became dyspneic and pulseless, another aspiration was done and 2,350 c.c. withdrawn. In thirty-one days 27 liters were aspirated. X-ray examination showed the bullet in front and a little to the right of the center of the twelfth dorsal vertebra. The patient's normal weight had been 160 pounds. After the first three aspirations he weighed 140 pounds and after the last one 128 pounds. The patient recovered.

In 1907 A. Bohne reported the second case. His patient was a twenty-one-year-old girl shot at the level of the second tracheal ring in the midline. The next day 2,100 c.c. of chyle were removed from the left pleural cavity. In the next five days two chest aspirations totaling 1,900 c.c. were made. Patient died. At postmortem, injury of thoracic duct was noted near the opening in the subclavian vein. Lungs showed pneumonia.

The third case, Julius Frohman encountered in the war, Aug. 19, 1914. His patient was a noncommissioned officer who was shot a little above and laferal to the left sternoclavicular joint. Because of signs of air and fluid in the left chest, he made a diagnosis of hematopneumothorax. The bullet had lodged against the

Received for publication April 21, 1936.
*From the Surgical Service of Mount Sinai Hospital.

spine in the middorsal region. Patient's condition was good until the seventh day, when he became orthopneic and cyanotic. His pulse was small, 160; his extremities were cold. He vomited, had a cold sweat and an irritative cough. There was dullness up to the second rib. His heart was displaced to the right. Frohman's diagnosis was hemorrhage, and he treated him for such with intravenous stimulation and infusions. Early the next morning the patient was *in extremis*, and Frohman decided that he had nothing to lose so would aspirate in spite of the hemorrhage. He was surprised to obtain a red-gray fluid which looked like blood mixed with pus. The patient was much improved after one liter had been withdrawn, so he continued until five liters had been removed by Potain aspiration. The picture changed immediately. The cyanosis and dyspnea disappeared, the pulse dropped to 102, and the extremities became warm. Frohman describes his surprise when the laboratory reported chyle and not pus. On September 17, 1,000 c.c. were again withdrawn. The bullet lay in the lower half of the left chest. The patient returned to field service November 28.

Franz Derganz reported his case also in 1915. Strangely enough in his case, too, the bullet entered near the sternoclavicular joint, but this time on the right side, and made its exit at the inner edge of the left scapula. The first aspiration was done eleven days after admission. Two liters were removed. The patient was transferred for rib resection, but when chyle was noted this was postponed and aspirations were done twice more. The patient recovered.

To digress a moment, in view of the point of entrance of the bullet in the two cases just noted, it is well to mention Hammesfahr's case of bilateral chylothorax in a boy, aged eight years, caused by a blow on the left sternoclavicular joint. There was no fracture and no penetrating wound. Nevertheless, the duct was injured apparently near its union with the subclavian vein. After tappings, the boy recovered. There have been other cases accompanied by fracture of the clavicle.

The fifth and sixth cases were reported by Elliott and Henry in 1917. Their first case was a soldier wounded August 8, 1916, by a piece of shrapnel which entered above the outer third of the right clavicle, and lodged under the skin at the apex of the left axilla near the posterior axillary fold. Eighteen hours later the man walked one mile. Four days later, subcutaneous emphysema and signs of fluid in the left chest were noted. His condition grew worse, and on the seventh day chest was aspirated and pink, opaque, creamy fluid obtained. Diagnosis of empyema was made. Thoracostomy 80 oz. sterile fluid (chyle) removed. Recovered.

Their second case was a man wounded Sept. 15, 1916. The bullet entered the middle of the neck just below the thyroid cartilage. No exit wound. On the fourth day he was desperately ill. Heart was displaced to right nipple. Signs of left hemopneumothorax. Temperature 98.5°. Chest aspirated, 90 oz. withdrawn. Fifth day culture reported streptococcus and *B. perfringens*, and 40 oz. removed. Rib resected. A mass was seen that was thought to be omentum and was replaced. Actually it should have been removed because it was clotted chyle. Clotted chyle frequently obstructed the drainage tube. Patient died. Autopsy: The bullet had passed through the trachea. These wounds were septic, but closed. The pleura was opened at the apex, but the wound in the thoracic duct was not found. The pleural cavity was filled with large masses of sour smelling clots that resembled buttery yellow curds.

In 1920, R. Drey reported the seventh case. His patient was a twenty-six-year-old man who had been shot on the right side of the spine, between the sixth and seventh cervical vertebras. Thirty-two days later the diagnosis of right pneumothorax with effusion reaching the fifth rib was made and confirmed by x-ray examination. Temperature 104°. Thoracentesis done. Pus and blood obtained.

Diagnosis of empyema. Eighth rib was resected for drainage. Ten days later chyle was demonstrated in sputum. An x-ray picture taken one and one-half years later revealed an adhesion of pleura at right costophrenic angle. No effusion.

The patient to be reported herewith was B. L., a female, aged twenty-four years, admitted to Mount Sinai Hospital January 10, 1935, because of a bullet wound of the chest. Examination: Bullet entered the outer half of the left nipple and passed out through the ninth interspace, 8 cm. to the right of spine. My examination seven hours later showed that the patient was quiet, respirations increased to 36, temperature 100.8°, pulse 136, blood pressure 110/70 mm. She had not spit up any blood. There was no swelling of breast. No ecchymosis, no powder marks, no subcutaneous emphysema. Heart borders were normal to percussion. Lungs: Breath sounds were clear. There was slight impairment at right base. There was a tender spot in left fifth intercostal space, under breast in midclavicular line. Patient stated she was dressed and standing up when shot and was wearing a brassiere—therefore, breast was somewhat elevated and held toward midline.

The abdomen was rigid throughout and very tender in the right hypochondrium. Liver not palpable. Liver dullness was present as high as the fifth interspace. This, together with slight impairment at right base, led me to believe that the bullet had hit the dome of the diaphragm and had possibly grazed the liver. It was evident that the heart and lungs had not been injured.

The next day temperature, pulse and respirations were lower. White blood cells 31,000; red blood cells 4,700,000; hemoglobin 85 per cent. Patient was more quiet. Dullness and diminished breath sounds from right midscapular region to base, led to diagnosis of fluid in right chest, probably hemothorax. Tenderness and spasm in abdomen was now limited to right hypochondrium.

Patient continued comfortable without much change for four days. On the night of January 14, she became dyspneic. Dullness had mounted to third interspace anteriorly. The first of a series of thoracenteses was done, and 3,100 c.c. of grayish red fluid were removed. Patient was relieved.

On the seventeenth day, she complained of pain in the left chest. A friction rub was both palpable and audible just below and to outer side of left breast (below entrance wound). Otherwise, breath sounds were clear. Right chest showed signs of refilling. The white blood count had dropped to 15,800 and the red blood count to 3,300,000. Ten days after admission, January 20, patient not only became extremely dyspneic but suddenly went into shock. Her blood pressure dropped to 80 systolic. Thoracentesis was done, 2,700 c.c. were withdrawn and patient rallied almost at once. She was given a transfusion of 500 c.c. The fluid obtained this time from the chest was reddish gray in color. The report from the laboratory examination of the fluid obtained at the first aspira-

tion showed innumerable red cells, no pus cells, and culture was sterile. The fluid from the second aspiration showed mononuclears and only few red blood cells and still no growth.

Two days later, January 22, the patient again went into collapse with severe respiratory distress. The right chest on percussion was flat throughout. The heart and the mediastinum were pushed far to the left. Thoracentesis yielded 2,800 c.c. of milky fluid, with slight reddish tint. On standing, it settled out in two layers—the upper looked like cream and the lower was pale red. Now the laboratory was asked to examine the fluid for fat because we suspected the fluid to be chyle. They reported 4.25 per cent fat. Therefore, our diagnosis of chylothorax from rupture of thoracic duct was confirmed.

The patient had now become very weak and exhausted. The red count had dropped to 2,750,000 and the hemoglobin to 70 per cent. She was now put on a fat free, high carbohydrate diet, in an effort to diminish the amount of chyle formed. We realized that the physiologists state that chyle flows up the thoracic duct because of the negative pressure in the chest. Therefore, we decided to leave the fluid in the chest to act as a tampon. But on January 23, and various succeeding days (see Chart 1) we were forced to aspirate because the patient went into collapse. She always presented the same symptoms at these moments, namely, severe respiratory distress, no pulse at the radial, a systolic of 70 or less, chest full of fluid, and heart and mediastinum displaced to the left. There was nothing left to do but aspirate to allow the heart and mediastinum to return and relieve the dyspnea. On January 23 continuous venoclysis was started with 5 per cent glucose. This was discontinued on January 24 because of phlebitis. A new vein was used on January 25 and disconnected on January 28 for the same reason.

The output of chyle did not appear to be diminished by the venoclysis, and as she seemed so susceptible to phlebitis, venoclysis was not repeated. By January 29, 15,300 c.c. of chyle had been removed from the right chest in six tappings. We noted that the fluid spurted out when the needle was introduced, and therefore we reasoned that if we could keep some positive pressure in the chest, it would tend to block the leak in the thoracic duct. We decided henceforth to withdraw only 1,000 to 1,500 c.c. of chyle at any one aspiration and also to do this before the patient showed a vascular collapse and respiratory distress. Thus, on February 1, daily tappings were necessary and by February 10 five more had been done, totalling 9,200 c.c. On February 8, a second transfusion was given and venoclysis started in the same vein. This had to be discontinued the next day.

In regard to our attempt to administer carbohydrates by means of continuous venoclysis of 5 per cent glucose, it is interesting to note that Beck's experiments would indicate that this is the wrong method to pursue. He found that lymphogogues injected into the blood stream are

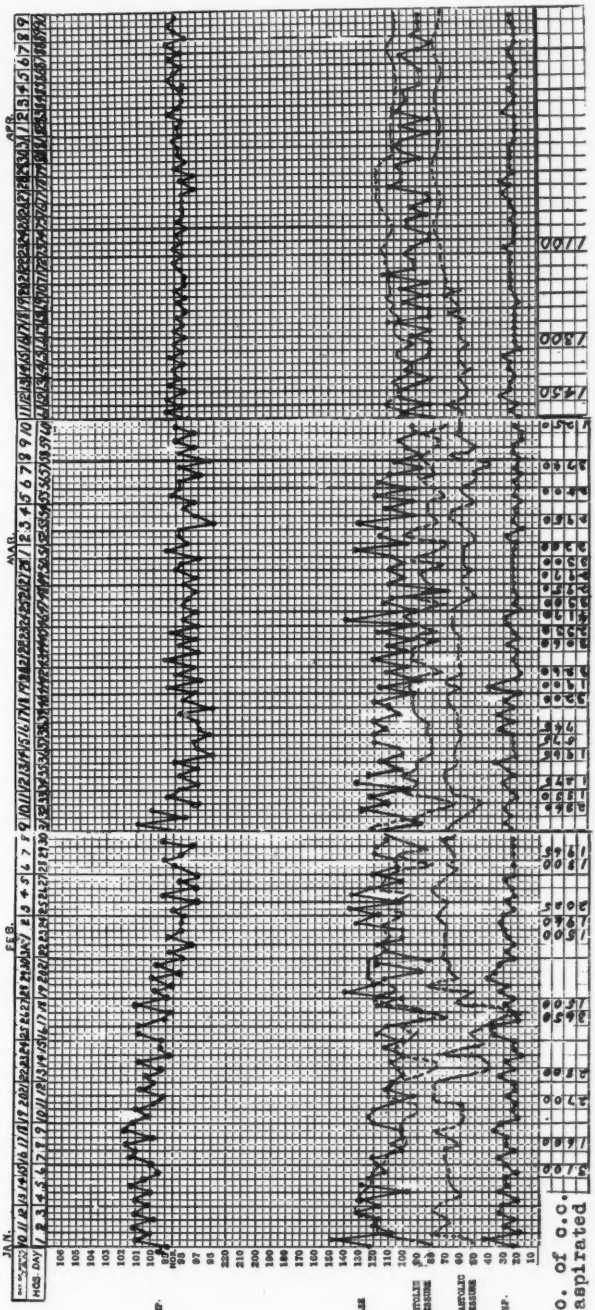
JAN.
FEB.
MAR.
APR.
TEMP.
PULSE
SYSTOLIC PRESSURE
DIASTOLIC PRESSURE
RESP.
No. of c.c. aspirated

Chart 1.

followed by a rise in lymph pressure and that dextrose is one of them. He also found a marked rise in lymph pressure following intravenous hypertonic saline, a slight rise after isotonic and no increase in pressure after hypotonic saline. Therefore, intravenous glucose cannot be recommended in chylothorax cases. So in retrospect, the patient lost nothing because of the fact the venoclysis could not be continued over a longer period of time.

On February 10 patient was again in collapse with signs of fluid filling the right chest. For the first time she was placed in an oxygen tent in the hope that it would relieve the hyperpnea. This was at 1 P.M., but after a trial of two hours without relief and because her blood pressure registered 80/60, a thoracentesis was again resorted to. This time, however, we replaced the fluid with air; 2,360 c.c. of lymph were withdrawn and now, although the fluid flowed out through the needle seemingly under positive pressure, the manometer showed negative pressure with inspiration. This we interpreted as evidence that the mediastinum yielded to the displacing fluid and therefore intrathoracic pressure remained negative. At 3:15 P.M., after 2,360 c.c. were withdrawn, 1,400 c.c. of air were introduced. Then, the manometer showed inspiration, 0 to expiration, +12, and the mediastinum was still displaced to left as shown by x-ray fluoroscopy. The patient was then placed back in the oxygen tent and felt fairly comfortable most of the afternoon, although dyspneic and with continued low blood pressure. At 8:00 P.M. the blood pressure was 68/32 and barely audible. At 9:00 P.M. patient had extreme respiratory distress and was pulseless. Therefore, 400 c.c. of air was removed and patient felt relieved. Pulse improved at the wrist, although the blood pressure reading was the same. Mediastinum was still displaced to the left. One hour later 600 c.c. more air was aspirated, and patient felt comfortable for the first time that day and was not put back in the oxygen tent. Blood pressure rose to 94/70.

The next morning, at fluoroscopy, we found the mediastinum in normal position. That afternoon another attempt was made to collapse the lung and put the right side at rest by a pneumothorax. Fluid was removed and air introduced and the pressures read as follows:

| | INTRATHORACIC PRESSURES |
|---|---|
| At beginning | −6 to −10 |
| Air introduced 320 c.c. | −8 to −12 |
| Air introduced 650 c.c. | −4 to − 8 |
| Air introduced 900 c.c. | −1 to − 6 |
| Total fluid removed 1,300 c.c. | |

Fluoroscopy at end showed good collapse of right lung and definitely lessened movement in right chest. However, the next day we had to remove 1,275 c.c. of lymph from the chest because the patient was in collapse as on former occasions.

Thus, we concluded that without fixation of the mediastinum we could not hope for any aid in the form of tamponade from either the chyle or the air, and that we could not put the right chest entirely at rest with pneumothorax.

By February 14, the patient was in good spirits except when she was in collapse but was definitely losing ground. She had lost much weight, was anemic, and her general appearance was poor. Believing that an attempt to find the tear in the thoracic duct, by operation, would be extremely difficult, as well as precarious, I decided to look into the chest with the Jacobeus instrument as a preparatory step. For this I am indebted to Dr. Stanley Sidenberg. He first withdrew 1,965 c.c. of cream-colored fluid and replaced it with some air. Then he introduced the Jacobeus thoroscope in the seventh interspace anterior axillary line. We saw many adhesions and what appeared to be a rent in the posterior mediastinum. However, I still thought the patient had a better chance without thoracotomy. Patient complained more of chest pain after this investigation, and her condition remained the same. We had to abandon our attempt to compress by restricting the aspirations to 1,500 c.c., and withdrew as much as necessary to give good relief.

On March 5, we decided to limit the fluid intake to 1,000 c.c. a day, in the hope that less chyle would form. On March 7, 2,700 c.c. were aspirated but from then on the amounts diminished rapidly to 1,250 on March 10, 1,400 on March 12, 1,300 on March 16. Then she went one week to March 23 before she needed another tapping and this yielded only 1,100. That was the last tapping. Convalescence from then on was uneventful. Although some fluid accumulated again, the patient was never distressed. The chest at the last x-ray examination, June 22, 1935, was clear. Patient was on a full diet and had no complaints. Her blood pressure was 108/64. The concentration of the blood after fluids were restricted is reflected in the blood count. The red blood count mounted to six million and the hemoglobin to 110 on March 9. When she left the hospital, April 13, she weighed 106 pounds. On June 22 she weighed 118½ pounds.

To reflect in what way this case resembled or differed from others, and how experimental work aided us or was of no avail in the management of the case. These points may be brought out best by reviewing the problems as they arose.

This patient showed but indistinct signs of fluid in her right chest seven or eight hours after she was shot. My notes read "slight impairment at right base and breath sounds somewhat distant." This, with rigidity throughout abdomen, could be explained by an injury to the diaphragm and dome of the liver. Twenty-four hours later, however, there were dullness and diminished breath sounds to the midscapular region on the right side, and the abdomen was tender and rigid only in the right hypochondrium.

The chest filled slowly and on the night of January 15, five days after admission, the patient suddenly went into vascular collapse with dyspnea. This condition necessitated the first tapping.

Now, as I review the other cases, they too had a period with no untoward symptoms, preceding the first collapse. In fact, Frohman, who had been treating his patient as a hematopneumothorax, when the patient suddenly went into collapse for the first time one week after injury, continued to treat him as such by intravenous infusions and stimulants, until in sheer desperation he aspirated and obtained fluid that looked like blood and pus. When his patient improved after one liter had been withdrawn, he continued until four liters more had been removed.

The suddenness with which the collapse occurred was quite appalling in my case and in others. As we later viewed the patient under the fluoroscope, it appears to be due to a displacement of the mediastinum, and perhaps an angulation of the vessels. It is not a slow steady process of falling pulse pressure and increasing dyspnea as occurs from hemorrhage, and it is also unlike recovery from collapse due to hemorrhage because it is prompt and complete without stimulation, as soon as relieved by aspiration.

As in other cases of traumatic chylothorax, especially those due to bullets, the condition was not suspected at the first tapping. The diagnosis was not made until the third tapping in spite of the fact that the report of a smear from the first aspiration read "Direct smear, innumerable red blood cells, no pus cells, no organism, no growth on culture." The fluid removed at the second aspiration was more grayish, and this time the report was more suggestive—"Moderate number of red blood cells. Very few mononuclear cells, no organism and no growth on culture." In order to get the fluid to separate into layers with the cream layer on top, we had to put the bottle in the ice box. The layers disappeared as the fluid was again brought to room temperature. Therefore, we may note that there are certain features peculiar to traumatic chylothorax. The fluid accumulates slowly in the chest without causing any discomfort or inconvenience to the patient. After three days or more, signs of vascular collapse and respiratory distress come on suddenly, resembling shock from hemorrhage. Temperature is usually not elevated. Aspiration of chest then gives immediate relief of symptoms. The fluid first obtained is grayish red resembling a mixture of blood and pus. The microscopic examination shows red blood cells and mononuclears and no pus cells to account for the grayish appearance. This clinical picture of sudden collapse and immediate relief after Potain aspiration, without any stimulation, combined with the withdrawal of grayish red fluid lacking in pus cells is a syndrome characteristic of chylothorax even before the laboratory report of fat cells in the chest fluid is returned. Without a microscopic examination for mononu-

clears and fat, the fluid may easily be mistaken grossly for pus and the patient operated on for empyema as in the first case of Henry and Elliott. But with this syndrome in mind such a mistake is avoidable.

Watts's case of traumatic chylothorax was unique in the length of time that it went undiagnosed. It shows this same syndrome. The patient was an inmate of an asylum and had attempted suicide. He plunged a knife into the left side of his neck downward from the suprasternal notch along the trachea. The wound was cared for and the patient was thought to be doing nicely on a diet of milk and eggs. Two days later, while retching, he expelled from his wound considerable fluid thought to be milk and eggs. Five days later, or one week after the attempted suicide, because of dyspnea and symptoms of sudden collapse, his left chest was aspirated, and "3 quarts of 'milk and eggs'" were obtained. Seven and one-half liters more were obtained in three tappings in the next twelve days, and then the patient was sent to the University of Virginia Hospital for gastrostomy, because the attendant thought that the patient's esophagus was cut, although x-ray examination failed to show it. This operation was performed as soon as the patient arrived on January 4, 1919. Three days later, when the left chest was tapped, the same type of fluid was again obtained, but this time examined at the laboratory and reported chyle, not "milk and eggs" as formerly thought. He died January 10.

Although the entrance and exit wounds in my case mark well the direction of the bullet through the chest, its path is open to theoretical discussion. A look at the cross-section of the chest at the level of the eighth thoracic vertebra shows what little leeway there is for a bullet to miss the viscera and how impossible it appears to hit the thoracic duct without injuring one of the large vessels. Furthermore, the duct itself is variable. The researches of Henry Davis resulted in his tabulating the various arrangements of the duct.

The embryologic form consists of a right and a left duct emptying respectively into the right and left subclavian vein with numerous anastomosing branches between the two ducts so that they resemble lattice work. The variations from this fundamental form are as follows:

1. The right duct through an anastomosing branch joins the left duct and thus empties into the left vein.
2. The opposite of this by which the left duct empties through the right.
3. Absence of the left duct below the upper branch so that the right duct appears to form a Y, emptying into both veins.
4. The opposite—absence of right duct, the left emptying into both veins.
5. Right duct alone and it crosses to empty into left vein.
6. Left duct alone and it crosses to empty into right vein.

7. Straight right duct into right vein.
8. Straight left duct into left vein.

The fifth is called normal by anatomists and represented 63.63 per cent of Davis' cases. The first variation comprised 27 per cent of his 22 cases. The fourth and sixth have not been found or reported.

It would seem, therefore, that an injury to a duct of the first two types would give a better prognosis for recovery than in any other type because of the collaterals. In fact, the type may be a determining factor in recovery.

The fact that there is no sign of effusion at first and that the fluid collects after three days or more in these bullet injuries of the thoracic duct, makes me believe that the bullet does not sever the duct but that a necrosis takes place along the path of the bullet and this necrosis slowly involves the thoracic duct which borders the path. Or it may become necrotic and rupture as the result of the vibration of the bullet much as the spinal cord is injured by a bullet striking the spine but not penetrating it.

The latent period and the sudden collapse of the patient appear in traumatic chylothorax without a penetrating wound, as well as in those due to bullets as stressed by MacNab and Scarlett. They believed that the collapse is due to an abrupt disturbance of pressure relations existing in the thoracic cavity with partial collapse of the lung due to sudden release into the pleural space of chyle which had been pocketed in the parapleural space.

Paitre[14] compared the sudden collapse of the patient to anaphylactic shock, and Lecene[15] mentioned sudden protein intoxication by resorption of protein from the pleura as a possible cause.

Like others before us we made frantic but futile attempts to check the flow of chyle by methods intended to increase intrathoracic pressure. We believed that if we could do that the pressure there would act as a tampon and stem the tide. Later, we learned that Lee had experimented with lymphatic pressure in the thoracic duct and found that when the flow was free in that duct the pressure was negligible, but in dogs with the duct occluded, pressure rose to 15 cm. of water and under sixteen minutes of forced breathing it reached 35 cm. of water. And we know that great pressure results in man from the chronic occlusion of the thoracic duct by tumors—even to the point of rupture. In other words, our attempts to create positive intrathoracic pressure to check the flow of chyle were doomed to failure because of the physiology of lymph pressure.

The first fat determination was made on January 22 (see Table I). This amounted to 4.25 per cent of 2,800 c.c. of fluid. This percentage dropped quickly, and on February 10 no butter fat was present. The specific gravity when taken varied from 1.010 to 1.029. Pseudochyle (or chyliform fluid) has a specific gravity less than 1.012 and less than

TABLE I

| DATE | NO. C.C. ASPIRATED | SPECIFIC GRAVITY | BUTTER FAT PER CENT | MG. PROTEIN PER 100 C.C. | ALBUMIN | GLOBULIN | W.B.C. | R.B.C. | (SAHLI) HEMOGLOBIN |
|---|---|---|---|---|---|---|---|---|---|
| 1/10 | | | | | | | 31,000 | 4,700,000 | 85% |
| 1/15 | 3,100 | | | | | | 15,800 | 3,300,000 | 75% |
| 1/17 | 1,600 | | | | | | | 4,000,000 | 66% |
| 1/20 | 2,700 | | | | | | 19,800 | 2,750,000 | 70% |
| 1/22 | 2,800 | | 4.25 | | | | 14,100 | 3,650,000 | 85% |
| 1/26 | 3,650 | | 0.2 | | | | 23,800 | 4,100,000 | 75% |
| 1/27 | 1,500 | | 0.5 | | | | | | |
| 2/ 1 | 1,500 | | | | | | | | |
| 2/ 2 | 1,950 | | | | | | | | |
| 2/ 3 | 2,050 | | 0.2 | | | | | | |
| 2/ 6 | 1,800 | | | | | | 8,000 | 2,850,000 | 90% |
| 2/ 7 | 2,000 | | | | | | | | |
| 2/10 | 2,350 | | Neg. | 1.87 mg. | 1.46 mg. | 41 mg. | | | |
| 2/11 | 1,350 | | Neg. | | | | | | |
| 2/12 | 1,275 | | 0.1 | | | | | | |
| 2/14 | 1,950 | 1.025 | Neg. | | | | | | |
| 2/15 | 550 | 1.022 | Neg. | | | | | | |
| 2/16 | 745 | 1.029 | Neg. | | | | | | |
| 2/18 | 3,200 | 1.014 | Neg. | | | | | | |
| 2/19 | 1,900 | | | | | | | | |
| 2/20 | 3,300 | 1.012 | Neg. | 1.02 mg. | | | | | |
| 2/22 | 3,100 | | | | | | 8,800 | 3,900,000 | 100% |
| 2/23 | 2,350 | | | | | | | | |
| 2/24 | 4,150 | 1.013 | Neg. | | | | | | |
| 2/25 | 3,300 | | | | | | | | |
| 2/26 | 2,950 | 1.010 | Neg. | 0.98 mg. | | | | | |
| 2/27 | 3,000 | 1.014 | Neg. | | | | | | |
| 2/28 | 3,300 | 1.012 | Neg. | 0.76 mg. | | | | | |
| 3/ 1 | 2,200 | 1.014 | Neg. | | | | | | |
| 3/ 3 | 2,950 | 1.013 | Neg. | | | | | | |
| 3/ 5 | 2,500 | | | | | | | | |
| 3/ 7 | 3,750 | 1.014 | 0.2 | 1.48 mg. | | | | | |
| 3/ 8 | | 1.012 | 0.1 | 1.18 mg. | | | | | |
| 3/10 | 1,250 | 1.012 | 0.3 | 1.16 mg. | | | 8,400 | 6,000,000 | 110% |
| 3/12 | 1,450 | | 0.2 | 1.04 mg. | | | | | |
| 3/16 | 1,300 | 1.014 | 0.2 | 1.014 mg. | | | | | |
| 3/23 | 1,100 | | | | | | | | |

0.3 per cent fat with no fat globules visible under the microscope. In order to learn whether we could identify in the chest fluid a fat that might be fed the patient, we fed her 5 gm. of trimerysterin three times a day for three days beginning February 1. The analyses of the fat in the chyle aspirated those days are shown in Table II. This was not re-

TABLE II

FAT ANALYSIS OF LYMPH COLLECTED

| | |
|---|---|
| *February 1, 1935:* | |
| Total fat 0.525 per cent of lymph | |
| Glycerolesters | 78.5 % of total fat |
| Phospholipoid | 12.44% of total fat |
| Cholesterol | 11.38% of total fat |
| *February 2, 1935:* | |
| Total fat 0.420 per cent of lymph | |
| Glycerolesters | 80.97% of total fat |
| Phospholipoid | 9.67% of total fat |
| Cholesterol | 9.36% of total fat |
| *February 3, 1935:* | |
| Total fat 0.455 per cent of lymph | |
| Glycerolesters | 72.7% of total fat |
| Phospholipoid | 15.7% of total fat |
| Cholesterol | 11.6% of total fat |

covered in the fluid aspirated, and probably one factor in the failure was that the fat was fed in capsules without being broken up and it passed through the alimentary canal untouched, thus had no influence on the percentage of fat in the aspirated fluid.

In reviewing the therapeusis of this case, I would say:

1. The elimination of fat from the diet is important and shows by diminished amount of fat in the aspirated fluid.

2. Limitation of water is the next important restriction to be observed.

3. There is no way of producing an intrathoracic tamponade by air or fluid.

4. Oxygen tent is no aid when the patient collapses from mediastinal displacement due to collection of fluid in the thoracic cavity.

5. Frequent aspiration is necessary to maintain life. This patient had 36 aspirations for a total of 79,800 c.c.

6. There is no advantage in leaving some of the fluid. In fact, partial aspiration means more frequent aspiration, and every puncture adds to the risk of infection.

7. From the review of the literature I would say that operation increases the mortality. Intrathoracic operations for control of leak of chyle from injury are mentioned in the literature, but I have not found any but an operation for empyema due to a complication or a mistaken diagnosis.

8. This case surpassed in the number of tappings and the total amount obtained, any bullet case reported, as well as any nonoperative

traumatic case I could find. J. Penn Milton reported what was an all time record for one aspiration from one chest, namely 300 oz. It took him six hours to do it. The patient had pulmonary tuberculosis.

9. A definite syndrome has been described common to all cases of traumatic chylothorax: (a) The patient apparently suffers no immediate ill effects referable to the cardiorespiratory system. (b) Fluid gradually accumulates in one or both chest cavities. (c) Three days or more after the injury patient suddenly goes into collapse characterized by dyspnea, orthopnea and fall in blood pressure, so that no pulse can be obtained at the radial. (d) Complete and instant relief from collapse by thoracentesis. (e) Fluid obtained reddish gray.

10. The mortality in the series reported herewith of eight cases of chylothorax due to bullet wounds is 25 per cent, which is lower than that for traumatic chylothorax from other causes.

11. In this series of 8 cases of chylothorax due to bullet wounds, 4 were on the right side and 4 on the left, although it is a condition more commonly found on the right side.

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# A MATCHED SET OF PERIOSTEAL ELEVATORS

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A MATCHED set of periosteal elevators has been designed which are of heavy construction and have large handles.† They are of uniform length, handle size, and weight (see Fig. 1). Matched irons have led to greater accuracy in golf; likewise, a uniformity of thoracoplasty instruments increases the ease and accuracy with which they are used.

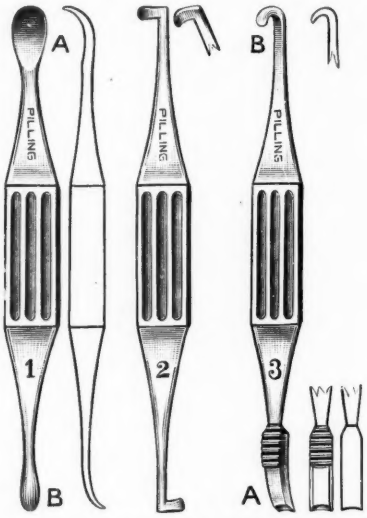


Fig. 1.—A matched set of heavy periosteal elevators with large handles. Weight 454 gm. (1 lb.). Handle 7×3×1.8 cm. Full length of instrument is 24.5 cm.

Instrument No. 1: For clearing outer and undersurfaces of all ribs.

Instrument No. 2: Rib edge stripper, reversed blades, push or pull, for use by assistant on all ribs below the second. For stripping edges of upper ribs, anterior portion as approached from inner surface.

Instrument No. 3: *A*, Sharp blade for clearing transverse processes and rib stumps. *B*, Hook for first rib.

It is advantageous to have available more than one type of periosteal elevator. The resection of ribs that are variously shaped, especially the upper ones, of the costal cartilages and the transverse processes requires variously shaped periosteal blades. The denudation of the ribs is also expedited if the first assistant is provided with an instrument. The

Received for publication, March 11, 1936.

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†Manufactured by George P. Pilling & Son Co., of Philadelphia.

edges may be stripped while the operator is clearing the outer and under surfaces. When different instruments are handled and used in rapid succession, the advantage of a matched set becomes apparent.

The following features have been embodied in the instruments here described:

1. All three instruments are of equal weight, length, and handle size.

2. The instruments are heavy, each weighing 454 grams (1 lb.).

3. The handles are large, measuring $7 \times 3 \times 1.8$ cm. The total length of the instrument is 24.5 cm.

4. Each instrument has a blade at both ends so that all necessary types (six working blades) are provided.

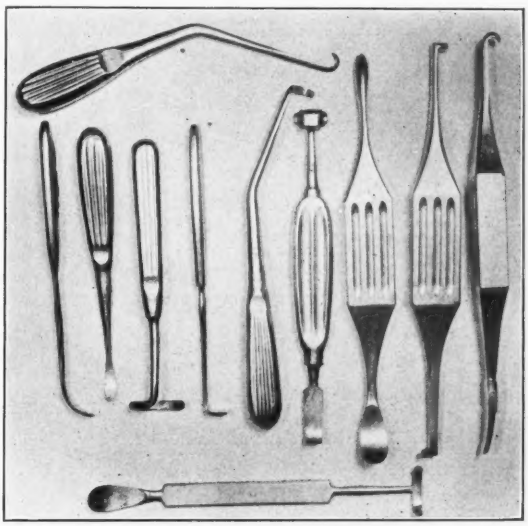

Fig. 2.—Various types of periosteal instruments available. A set of the instruments here described is included for comparison of total length, shaft length, handle size, et cetera.

5. The shafts of all instruments are straight so that they can be used on either side of the patient and on either side of the rib without confusion.

The instruments, therefore, answer the four major objections which I have found to the various periosteal elevators now on the market.

1. There has been no uniformity of length, weight, handle size or of the distance between the handle and the working blade in any two or more periosteal instruments available. With a lack of uniformity in the instruments with which similar motions are carried out, it is more difficult to develop rhythm and accuracy in operating (see Fig. 2).

2. All instruments I have previously used have been too light in weight. It takes considerable muscular effort on the part of the operator to hold a light instrument on the rib in carrying out periosteal stripping. A heavy instrument by virtue of its own weight glides along and frees the periosteum with minimal effort. This is an important consideration when a number of thoracoplasties are done in one day. The

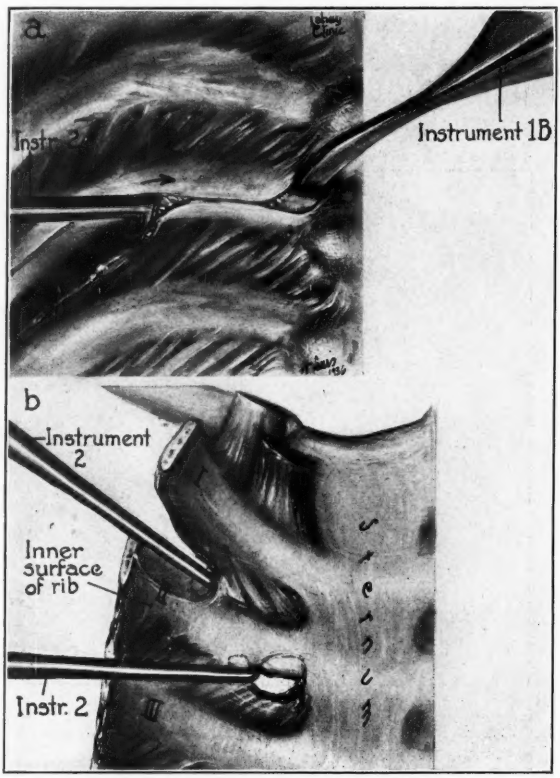


Fig. 3.—*a*, Small end of Instrument No. 1 is used to start the rib edge stripper. A separate instrument, the rib edge stripper, is used by the assistant.

*b*, Drawing showing Instrument No. 2 in use in clearing the edges of the upper ribs anteriorly from their undersurfaces.

instruments here presented are constructed of solid steel and have solid steel handles. Each instrument weighs three to four times that of the ordinary periosteal elevator.

3. Previously designed instruments have relatively small handles which are difficult to grip firmly (see Fig. 2).

4. Instruments heretofore available were not designed with particular reference to treatment of the upper ribs. Double-bladed rib strippers

and encircling blades of the Doyen type are satisfactory when used on the shafts of the lower ribs but do not work well posterior to the angle of the rib or on the upper ribs. The edge of the anterior portions of the upper three ribs can be separated with greater ease by working from the undersurface. It is difficult to use a stripper with a double blade on one end because of the danger of the reversed blade injuring the lung. Instruments with angled shafts for use in stripping in one particular direction lead to confusion, since all ribs cannot be approached from the same position. A straight shafted instrument with blades that strip on either the push or the pull of the stroke is time saving and therefore more practical.

*Instrument No. 1.* Blade A is similar to the periosteotome of the Matson[1] instrument. It is used to clear both the outer and the inner

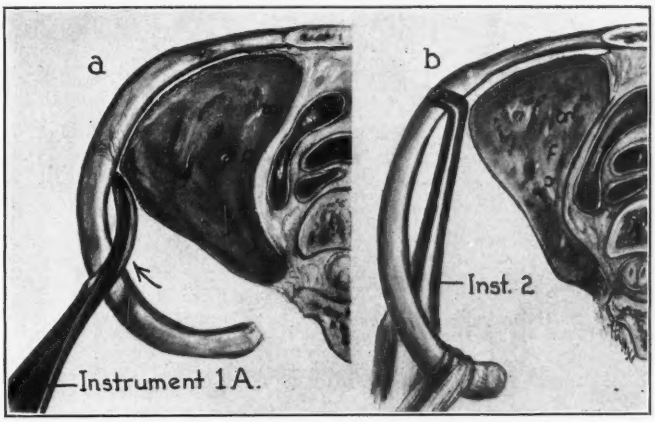


Fig. 4.—*a*, Drawing illustrating the use of Instrument No. 1 in clearing the undersurface of rib anteriorly. The curve of the blade prevents injury to the underlying lung.

*b*, Illustration showing advantage of single-bladed rib edge stripper as used from the undersurface of the rib, anterior portion.

surfaces of the ribs. Blade B is the same general type as blade A, but much narrower. It is designed for clearing the posterior angle and is narrow enough so that it can be thrust directly through the intercostal muscle bundle in starting the clearance of the rib posteriorly (see Figs. 3 and 4).

*Instrument No. 2.* This instrument is solely a rib edge stripper with reverse single blades on each end. It is used by the assistant on all ribs below the second while the operator clears the outer surface and the posterior angle with Instrument 1 (see Fig. 3). The angle of the upper ribs makes it impossible to strip the edges completely around to the sternum from the outer side. The blade of Instrument 2 is so designed that the operator can clear the edges of the anterior portions of ribs one,

two and three by working from the inner aspect after the periosteum from the undersurface of these ribs has been separated by Instrument 1 (see Figs. 3 and 4*b*). The stripping blade on each end of the instrument is a single one, thus minimizing the danger of injury to the underlying lung in carrying out this maneuver from the undersurface of the rib. Double-bladed rib edge strippers of the Matson or Alexander[2] type cannot be used in this location with safety because of the opposite projecting blade.

*Instrument No. 3.* Blade A is similar to the blade of Alexander's periosteal elevator. The cutting edge is sharper and more curved. It

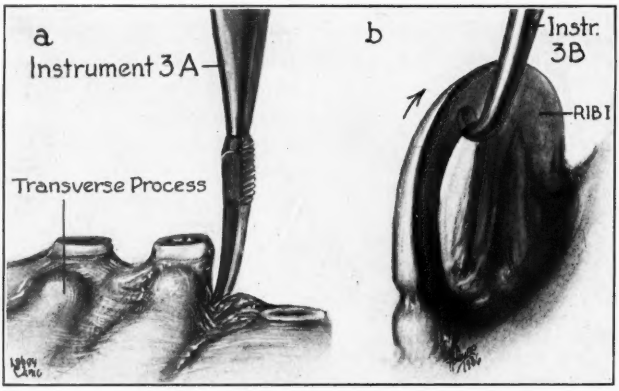


Fig. 5.—*a*, Illustration showing sharp-bladed instrument clearing transverse process. *b*, First rib hook clearing periosteum from lesser curvature of rib.

has two purposes: clearing the inferior edge of the first rib and clearing the posterior rib stumps and transverse processes (see Fig. 5). Blade B is similar to the Sauerbruch hook for stripping the attachments of the anterior scalene muscle and periosteum from the medial edge of the first rib. It is also useful to hold this rib after it has been sectioned posteriorly and during the time that it is being denuded anteriorly.

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# A CONTINUOUS AUTOMATIC WATER SUCTION APPARATUS FOR ASPIRATING CAVITIES

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THE description of this apparatus is presented because of its wide diversity of applications, ease of construction, and low cost, making it readily available in hospitals of any size or state of financial embarrassment. In fact, it is so readily made that there is no reason why it should not be available to the practitioner for home use when necessity demands. The need for such a device became apparent when the excessive cost, bulkiness, unreliability, or necessity for constant attentions of other forms of apparatus generally used, was observed. The only requisites for its construction and operation are about seven dollars' worth of material, an hour or so of time in any laboratory, and a water faucet.

For ease in understanding its construction and operation, a photograph of the finished product and a schematic diagram of its construction are presented.

The materials used in the assembly are:

| | |
|---|---|
| One filter pump, larger size | $1.75 |
| Three pyrex test tubes of about 200 x 32 mm. size | 1.20 |
| Six feet of glass tubing, 8 mm. | .25 |
| Ten feet of rubber tubing | 1.00 |
| One pound commercial mercury | 2.50 |
| One gallon jug fitted with rubber cork | |
| Three rubber corks to fit test tubes | |

The construction is quite fully explained in the drawing showing filter pump A exerting suction into tube B. From there it is successively transmitted to tubes C, D, and finally into collecting jug F. Tube B is inserted so that with a sudden decrease of suction from the pump such as might come from the water being turned off, the vacuum in the system beyond will not draw water from the tubing connecting A and B into the regulating tube C. Tube C is fitted with a straight tube G, leading to near its bottom. In this tube is placed a variable amount of mercury by means of which the degree of suction is regulated; the greater the depth to which G is submerged, the greater the suction. C in turn is connected to D to which is attached a mercury manometer E. By means of this manometer the actual negative pressure can be readily measured and observed. From D the vacuum is carried over to collecting jug F which is connected directly to the cavity to be aspirated, by means of rubber tubing. Tube H holds the reserve supply of mercury.

The contents of tube C are really the most important parts of the entire device, for by means of these the final vacuum in the collecting jug can be regulated at

Received for publication September 19, 1935.

any desired level regardless of how much suction is exerted by the pump from turning on the water full force. As the vacuum is built up in tube C, the mercury in tube G is pulled down by the vacuum, allowing air to rush in through it and so keep the vacuum at the desired level. When greater vacuum is desired, more mercury is placed in the tube. By means of the manometer E, it is observed that, although the suction from the pump A may vary widely, the final level of the vacuum in tube D or collecting jug F is very constant so long as the pump exerts the minimum necessary force. This manometer consists merely of a glass tube bent to the shape pictured and partially filled with mercury. In operation it has been found advisable to adjust the rate of water flow through the pump so that there is a slow steady bubbling of air through the mercury, from tube G. If air bubbles very rapidly, it means that more water force is being used than necessary. This is not only wasteful but also adds to the noise, which might be somewhat disturbing to the patient.

Once the apparatus is set in operation, the only attention it needs is to empty the collecting jug F when it becomes filled with aspirated fluids.

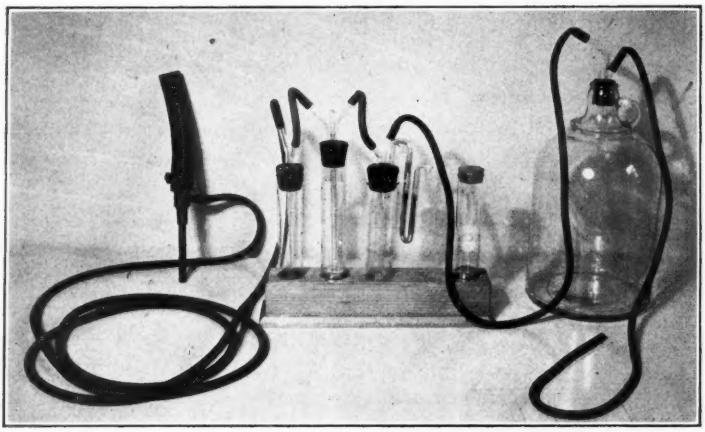

Fig. 1.

This apparatus has been used for aspirating stomach contents through a Levine tube in case of dilatation complicating peritonitis or surgical procedures. Following this it was found very helpful in a case of vesicovaginal fistula following hysterectomy. By keeping the bladder constantly empty the fistula closed very promptly after other measures used over a period of time had been unsatisfactory. From this its use in speeding the closure of the suprapubic wound following prostatectomy is suggested, after drainage has been established through a urethral catheter. More lately it has been found of great value in operative cases following pulmonary lobectomy. In these cases a tube has been placed into the pleural cavity and the wound closed as tightly as possible. Soon after the apparatus is attached, examination shows the degree of pneumothorax to be negligible. Later on, accumulated pleural fluids are

aspirated as they accumulate with no further interference. In cases of empyema treated by closed drainage, equally good results are obtained. By exertion of a negative pressure upon the drainage tube the pus will continue to drain after it becomes too thick to drain freely by gravity alone. In cases of traumatic pneumothorax or bronchopleural fistula it should be found equally valuable, for by continuous suction into the pleural cavity the collapse of the lung could be greatly lessened.

In operation it has been found that most satisfactory results are obtained by adjusting the negative pressure at between four and twenty mm. depending upon the use to which it is being put. A practical

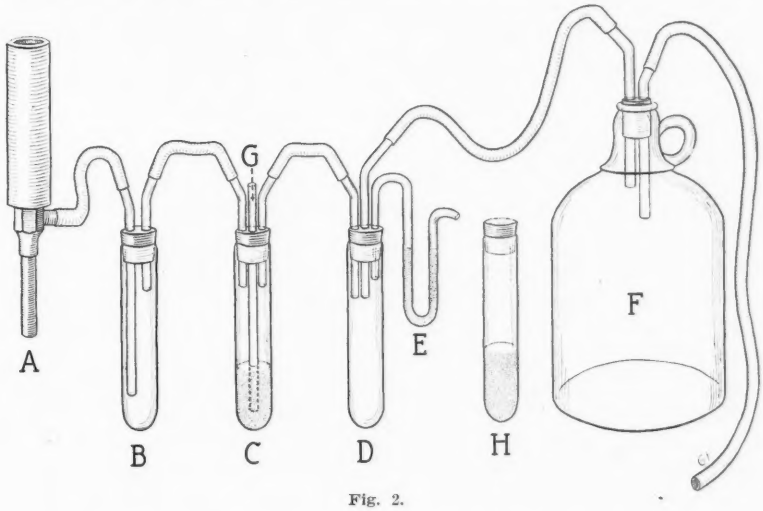


Fig. 2.

point to remember in reading the manometer is that with such a U manometer the negative pressure is measured by the entire distance between the two columns of mercury.

Undoubtedly as its use continues numerous other applications will become apparent.

## SUMMARY

There is presented a very economical, easily constructed, automatically operating, apparatus for continuous aspiration of cavities, having a wide diversity of uses. To meet this diversity of uses the degree of vacuum, which can be readily measured at all times, is easily adjusted and once set in operation cannot mount to the extent of becoming dangerous as would be the case if the suction were exerted directly from the water pump.

# PNEUMOTHORAX DECOMPRESSOR*

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THE successful management of spontaneous pneumothorax depends upon the nature of the pulmonary fistula. In the simple form, rest in bed, with elevation of the patient's back to relieve dyspnea, and the use of morphine for pain are usually sufficient. The lesion heals naturally with granulation tissue, which prevents the passage of air into the pleural cavity and permits the lung to reexpand and resume its normal function. In these cases the withdrawal of air is rarely necessary.

The problem is difficult and not without danger in valvular pneumothorax, with marked displacement of the heart and the mediastinum. In these circumstances the air is locked in the pleural cavity, and its removal is necessary. This may be accomplished by means of Robinson's artificial pneumothorax apparatus, in which the usual manipulation of the bottles is reversed and the air withdrawn until the desired intrapleural pressure is obtained. Following this, the pneumothorax needle is removed and then reintroduced later, at intervals, in order to determine the degree of intrapleural pressure. In cases with rapid accumulations of air, the needle is allowed to remain in situ in order to avoid delays when the immediate reduction of pressure is indicated. A disadvantage of this method is that it provides no means for maintaining an even intrapleural pressure, since with the periodic withdrawal of air the lung is alternately compressed and expanded. Thus, the pulmonary lesion tends to remain patent, and this allows the pneumothorax to continue and ultimately leads to the development of an empyema.

The pneumothorax decompressor was designed in order that the air in the pleural cavity could be released automatically. The apparatus consists of a discharge jar A which is filled one-half with water; an air discharge tube which may be elevated or lowered by turning the geared set screw D on ratchet C; a water manometer H for determining the intrapleural pressure, and jet valve G connected with valve E; a rubber tube which connects the pneumothorax needle with the apparatus; and a special pneumothorax needle with an adjustable circular disc for fastening it with tapes to the chest wall.

The rate of discharge and the amount of air to be removed should be governed according to the degree of intrapleural pressure that is de-

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Received for publication, December 15, 1935.

sired. This is accomplished by changing the position of the discharge tube. With the tube elevated the column of water is correspondingly reduced, resulting in less resistance to the pressure in the pleural cavity. Thus, the flow of air will be accelerated and, conversely, with lowering of the tube the resistance to the pleural cavity will be increased and the passage of air retarded. With the apparatus adjusted for a given intrapleural pressure the passage of air will continue automatically, depending actually upon the depth of the pulmonary movements and

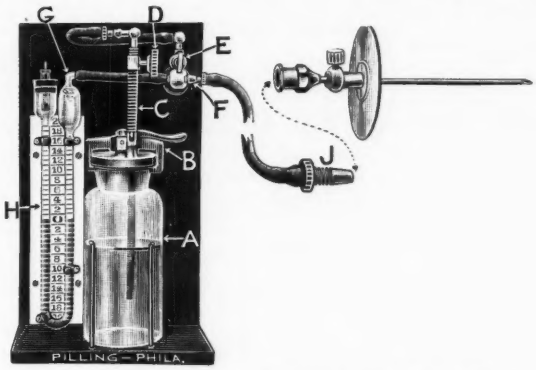


Fig. 1.—The pneumothorax decompressor with needle.

the size of the opening in the lung. While the water contained in the jar serves as a buffer and regulates the passage of air, it also prevents the suction of atmospheric air into the pleural cavity.

Patients treated with the pneumothorax decompressor* are more comfortable and experience less shock and sudden pulmonary manifestations than when air is withdrawn intermittently. Since the sudden expansions of the lung are prevented, there is a tendency for the lesion to heal.

*The apparatus is manufactured by the George P. Pilling and Son Co., Philadelphia, Pa.

# Department of Reviews and Abstracts

CONDUCTED BY DUFF S. ALLEN, M.D., ASSOCIATE EDITOR

## Selected Abstracts

**Twenty Years' Experience With Artificial Pneumothorax: a Study of 460 Cases.** A. F. Miller et al. Canadian M. A. J. **33**: 650, 1935.

The authors report that in their group of moderately advanced pulmonary tuberculosis, those patients having pneumothorax therapy were well and at work in a ratio of 2½:1 to those patients not having this type of therapy. In the far-advanced cases of tuberculosis the ratio was 5:1.

There were very few ill results from pneumothorax therapy. In no instance was death directly due to this treatment.

As for complications, in the past six years 36 per cent of patients having pneumothorax treatment developed pleurisy with effusion, which did little or no harm. In 8 per cent of their cases tuberculous empyema followed pneumothorax, this condition adding to the gravity of the prognosis. In 8 per cent of the cases there was contralateral extension, 5 per cent had adhesive pleuritis, 2 per cent had spontaneous pneumothorax, 0.4 per cent had hemothorax and 0.4 per cent had surgical emphysema.

The authors have not induced pneumothorax in patients with minimal tuberculosis, but they feel that in about 10 per cent of cases of minimal pulmonary tuberculosis patients might benefit from pneumothorax or phrenicectomy.

The most suitable cases for pneumothorax therapy are the unilateral ones. In their series, however, only 19.3 per cent were unilateral, the remaining 80.7 per cent having disease in both lungs.

The decision as to when to start pneumothorax treatment is based upon clinical, x-ray and laboratory examinations. A poor pneumothorax should not be continued indefinitely, since operative means should be considered at a time when optimum benefit may be derived from surgical intervention.

The authors show a series of 75 cases wherein a phrenicectomy alone or a phrenicectomy following an ineffectual pneumothorax re-

sulted in the closure of cavity in 33.3 per cent of the cases, partial closure of cavity in 43.3 per cent and tubercle bacilli disappeared from the sputum in 35 to 40 per cent of the cases.

*Henry L. Cabitt.*

**The Use of Helium in the Treatment of Asthma and Obstructive Lesions of the Larynx and Trachea.** A. L. Barach. Ann. Int. Med. **9**: 739, 1935.

The specific gravity of helium being one-seventh of nitrogen, a mixture of 80 per cent helium and 20 per cent oxygen has one-third the weight of a comparable volume of air. Since the pressure required to move an object is in general proportion to its weight, it was assumed that a relatively light respirable gas could be breathed with less effort in clinical conditions in which difficulty in ventilating the lungs was present.

Inhalations of this combined helium-oxygen mixture were given to four patients with severe asthma with marked benefit. In three patients a grave state of status asthmaticus and refractoriness to adrenalin were removed by inhalations of this mixture of gases. This therapy has special value in the treatment of patients with asthma persisting after adrenalin and in status asthmaticus.

Graphic records of the quantitative and qualitative changes in pulmonary ventilation after use of this helium-oxygen gas mixture revealed: (1) decrease in pulmonary ventilation, (2) decrease in pulmonary pressure, (3) relative and absolute diminution in the length of expiration, (4) increased rest period between respiratory cycles.

The author reports two cases of severe obstructive dyspnea in infants, one with laryngeal and the other with tracheal obstruction, in which inhalations of this gas mixture gave marked relief.

*Henry L. Cabitt.*

**Purulent Pericarditis.** A. M. Shipley, and N. Winslow. Arch. Surg. **31**: 375, 1935.

This is a report of five cases of purulent pericarditis in which treatment was by pericardiotomy and review of ninty-nine cases found in the literature from April 30, 1927, to January 1, 1934. All cases not surgically treated and those treated by aspiration alone have a 100 per cent mortality. The surgical mortality is 50 per cent. Much emphasis is placed upon early diagnosis and immediate surgical intervention. The costoxiphoid route is the most advantageous. This route necessitates the resection of the left fifth, sixth, and seventh costal cartilages, and when more space is needed a portion of the sternum. The prognosis depends upon the time of operation, the type of the organism, and the original condition of which the pyopericardium is a

complication. Purulent foci elsewhere should be constantly looked for and promptly treated. Failure to do this will alter the prognosis considerably. In the series, 85 per cent of the patients were under thirty years of age. Seventy per cent of the patients were males, and 30 per cent were females. Contrary to the older contentions, postoperative adhesive pericarditis was encountered in only 5.13 per cent of the cases; the remaining 45 per cent were able to continue with the normal activities of life.

*W. D. Thompson, Jr.*

**Factors Causing Bronchiectasis: Their Clinical Application to Diagnosis and Treatment.** W. P. Warner. J. A. M. A. **105:** 1666, 1935.

This is a survey of 110 cases of bronchiectasis, which were thoroughly studied and followed for varying periods of time up to eight years. It was found that the bronchiectasis began with a known illness in 59 per cent of the cases. Pneumonia predominated with 30 per cent. The remaining 41 per cent of the cases had an insidious onset. The initial fault in bronchiectasis is damage and subsequent weakening of the bronchial wall, probably caused by a nonspecific infection. As a result of the loss or impairment of its elastic and muscle tissue the bronchus becomes more greatly dilated on inspiration and less contracted on expiration. This, if continued, will cause permanent damage. Atelectasis and fibrosis of the parenchyma increase the inspiratory pull on the bronchus, thereby causing greater dilatation. Central bronchial obstruction will frequently work as a ball valve, allowing air to rush in but to escape with difficulty. This increased bronchial pressure alone or when combined with the increased inspiratory pull as found in fibrosis and atelectasis of the parenchyma is an important factor in the development of bronchiectasis when the bronchial wall is already weakened. A diagnosis of congenital bronchiectasis should be made with great hesitation; such a condition usually cannot be proved either clinically or pathologically. The local symptoms of bronchiectasis are cough and sputum, influenced by posture; the sputum moderate in amount, often accompanied by blood spitting, usually not foul smelling, but practically always chunky. General symptoms are dependent upon the condition of the parenchyma. Fifty-two per cent of the patients presented at least one attack of pneumonia after the onset of the bronchiectasis. The physical signs are dependent upon the condition of the parenchyma; however, the commonest sign is the medium crackling râles persisting at one or both lower lobes. In bronchiectasis the plain roentgen examination is helpful in ruling out other possible conditions. When atelectasis is present, bronchiectasis should be strongly suspected. Roentgen examination after injection of radiopaque oil is the most important diagnostic

procedure. The prognosis depends upon the conditions present in each individual case. Twenty-three per cent of these patients died after having the disease for an average of nine years. Artificial pneumothorax may be helpful in treatment of the early cases before permanent dilatation has occurred. Bronchoscopic drainage often improves postural drainage by removing some central bronchial obstruction. Lobectomy should not be considered unless the patient has considerable disability.

*W. D. Thompson, Jr.*

**Lung Puncture in Lobar Pneumonia.** S. W. Sappington and Grant O. Favorite. Am. J. M. Sc. **191**: 225, 1936.

The authors recommend lung puncture, when sputum is not available, for the early diagnosis and typing in pneumonia. They describe a technic of lung puncture which, according to the authors, is simple and safe. In a study of the literature and of their own cases there have been no reports of untoward results from this procedure.

The authors report 60 cases (57 due to the pneumococcus and 3 due to the streptococcus) in which positive culture was obtained in 90 per cent of the cases, half of these within six hours. In 25 cases in which both the lung puncture and the sputum pneumococcus were typed there was a 100 per cent agreement.

*Henry L. Cabitt.*

**Bronchial Catheterization.** Samuel A. Thompson. Am. J. Surg. 260, 1936.

The author states that this procedure has many values:

1. Diagnostic:
   a) Collection of smears and specimens.
   b) Bronchography.
   c) Bronchopulmonary localization.
2. Therapeutic:
   a) Aspiration and insufflation.
   b) Irrigation.
   c) Medication.
3. Research.

The author describes the technic of bronchial catheterization and the types of catheters used. Knowing the relative distance in centimeters from the teeth to the bifurcation of the trachea and divisions of the various lobe bronchi, since the catheter is calibrated in centimeters, the tip of the catheter can easily be placed opposite the divisions or lobe bronchi desired. With the exception of the right upper lobe bronchus,

catheterization of any lobe bronchus is usually possible without the aid of the fluoroscope. The procedure can be carried out in the office. This procedure is not offered as a substitute for bronchoscopy, since a careful bronchoscopy usually precedes it.

*Henry L. Cabitt.*

**Pulsating Tumors of the Sternum.** George Crile, Jr. Ann. Surg. **103**: 199, 1936.

In the differential diagnosis of pulsating tumors of the sternum, one must consider aortic aneurysm and neoplasm of the sternum. This differential can be ascertained by the x-ray examination and the fluoroscope. In a perusal of the literature no verified case of pulsating primary sarcoma of the sternum was found. In 18 cases reported, nine were metastatic from a primary hypernephroma and nine metastatic from a primary malignant adenoma of the thyroid.

The usual signs and symptoms are sternal pain and the appearance of a tumor over the sternum. In every case the tumor occupied the upper part of the sternum with the exception of one case in which the tumor involved the entire sternum. The tumor is usually described as of firm consistency. The average survival of the patient after the appearance of the first symptom was about three years.

In view of the naturally slow development of the disease it is probable that more conservative treatment, such as irradiation, is preferable. If the primary tumor is operable and the patient is willing to have both the primary tumor and the metastatic sternal lesion removed, then a cure is possible. There is, however, no such case on record. Another difficulty is to rule out undetectable generalized metastases.

*Henry L. Cabitt.*

**Congenital Absence of the Pericardium.** William E. Ladd. New England J. Med. **214**: 183, 1936.

The author presents a case of congenital absence of the pericardium. In a search of the literature 68 similar cases were found. The case reported here is the only one recognized during life. This condition is compatible with an active life of normal duration. The author operated on a patient for a left-sided diaphragmatic hernia and during the course of the operation noted the absence of the pericardium.

The question arises as to the effect of atmospheric pressure on the heart. Patients who have had the pericardium opened for pericarditis or other reasons do not suffer from having the heart exposed to atmospheric pressure. In the case reported the air was allowed to absorb slowly with a perfect outcome.

*Henry L. Cabitt.*